ISSN 1644-0692
www.acta.media.pl

Acta Sci. Pol. Hortorum Cultus, 15(3) 2016, 45-57

FLOWERING PHENOLOGY OF *Weigela florida* Bunge AND THE EFFECT OF COLOR CHANGE IN ITS FLOWERS ON THE BEHAVIOR OF VISITING INSECTS

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Abstract. Over the period 2007–2009, a study was conducted on the biology and abundance of flowering of *Weigela florida* Bunge and the effect of color change in its flowers on the behavior of pollinating insects. In the climatic conditions of south-eastern Poland, the flowering of the studied taxon started at the beginning of the second 10-day period of May and lasted from 4.5 to 7 weeks. Single *W. florida* flowers lived on average for 6.5 days. Bumblebees were predominant among insects visiting the flowers of *Weigela florida*, while honey bees visited them in lower numbers. Insect visitation to different-aged flowers was found to vary. The pollinators most frequently visited young flowers with bright pink petals and a yellow or orange nectar guide in the throat of the corolla, while they avoided older dark red flowers with a red-carmine nectar guide.

Key words: *Weigela*, flowering, flower color change, insect behavior

INTRODUCTION

The flowers of entomophilous plants are characterized by numerous traits that directly affect their attractiveness and as a consequence the behavior of visiting insects. One of such traits is flower color change that can be observed in many representatives of more than 74 botanical families [Weiss 1991]. The increased interest of insects in visiting flowers with a specific color has a beneficial effect on plant reproductive success, which is strictly dependent on the number and frequency of pollinator visits. All parts of the flowers or only some of them can change the color [Weiss 1995, 1997, Weiss and Lamont 1997]. Apart from the color, the attractiveness of flowers to pollinat-

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ing insects is also determined by their size and the number of simultaneously open flowers on the plant [Cruzan et al. 1988, Klinkhamer et al. 1989].

Flower color change is very common in, among others, representatives of the family Caprifoliaceae, in which the genus *Weigela*, comprising 12 shrub species native to the Far East – Japan, Korea, and China, is one of the genera that are represented in greater numbers [Ohba 1993, Kim and Kim 1999, Zhang et al. 2012]. In Poland *Weigela florida* is commonly grown and due to its high decorative qualities as well as its long flowering period and very abundant bloom it is attracting increasingly greater interest. This species is most often found singly or in groups in parks and gardens. *Weigela florida* is also planted near other deciduous or coniferous shrubs where after the end of flowering it is a good background for perennials blooming in summer due to its intense green-colored or bicolored leaves. Besides, cut leafy stems are often used as a valuable floristic material [Rubinowska et al. 2012].

The aim of the present study was to:

– investigate the flowering pattern and abundance of *Weigela florida* Bunge shrubs in the conditions of Lublin;

– identify the morphological characters of the flowers of *Weigela florida*;

– determine the effect of color change in its flowers on the behavior of visiting insects.

MATERIAL AND METHODS

Over the period 2007–2009, a study was conducted on the biology and abundance of flowering of several-year-old *Weigela florida* Bunge shrubs. Observations were carried out in urban green spaces in Lublin (south-eastern Poland, 51°14'N, 22°34'E). The time and duration of flowering of this taxon as well as the duration of inflorescence flowering and the flower life span were determined.

Detailed observations of flowering dynamics of this species were carried out in 2007. The observations, on 10 randomly selected shrubs, began when the first flowers appeared and they were continued until the last flowers faded. The generative development stages of the shrubs were determined following the recommendations of Łukasiewicz [1984] with some modifications [Stawiarz and Wróblewska 2013]. The time when the first several flowers unfolded and opened up was considered as the beginning of flowering of this taxon. The full flowering stage was when from 50 to 75% of flowers on the shrubs were open, while the time when about 100% of flowers were faded was considered as the end of flowering. The number of all open flowers and the number of flowers which opened up in the successive days of the shrubs flowering period were recorded daily on one inflorescence stem on each of the 10 shrubs. Flowering abundance of the shrubs was determined based on the number of flowers per inflorescence, number of inflorescences per one running meter of stem, and number of stems per shrub.

The observations of the life span of single flowers were carried out from the bud stage until petal fall. The individual flower development stages were determined using the phenological signs of Krotoska [1958], with the following stages distin-

guished: loose bud, the beginning of flowering, full flowering, and the end of flowering. In each year of the study, the flowering pattern of single flowers was observed on 10 randomly selected inflorescences located on different shrubs. In each season, the observations were conducted at two different times under varying weather conditions.

Morphological measurements of the *Weigela florida* flowers were made at two times – at the beginning of flowering and at full flowering of this taxon. For this purpose, the following characters were determined for 10 randomly selected flowers sampled from different shrubs: petal length (A), corolla tube length (B), corolla lobe length (C) as well as flower diameter (D) and corolla tube diameter at the tube apex (E) (fig. 1). The color change of the petal and of the nectar guide in the throat of the corolla was observed with age during the individual flower development stages were recorded.

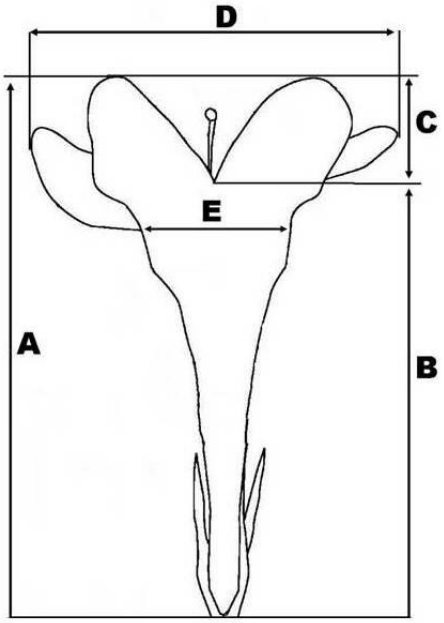

Fig. 1. Diagram of the flower parts measured (A – petal length, B – corolla tube length, C – corolla lobe length, D – flower diameter, E – corolla tube diameter at the tube apex)

During full bloom of the *W. florida* shrubs, the behavior of insects visiting on different-aged flowers was observed daily at different times of the day.

Statistical analysis of the study results was performed based on variance analysis (ANOVA) and Tukey's multiple t-tests at a significance level of $\alpha = 0.05$. Calculations were done using Statistica 6.0 software.

RESULTS

In the conditions of south-eastern Poland, the flowering of the *Weigela florida* Bunge shrubs began on May 12 and ended in the second or third 10-day period of June throughout the study period. The average flowering duration for this species was 40.3 days. In the first year, the flowering period of the shrubs was shortest – 32 days, while it was longest in 2009 – 48 days (tab. 1). The flowering duration of this species was affected by varying weather conditions in the successive years (tab. 2). In the first year of the study, the highest average temperature for the months of May and June during this season had an effect on the shortest flowering period. An exceptionally long flowering period of this species in the third year of the study was due to lower air temperature during the blooming period of the shrubs as well as due to medium and abundant rainfall in June (tab. 2). Full bloom of this taxon occurred in the second week of its flowering period, i.e. at the turn of the second and third 10-day period of May when daily from 12000 to 16000 open flowers were recorded on the individual shrubs (fig. 2).

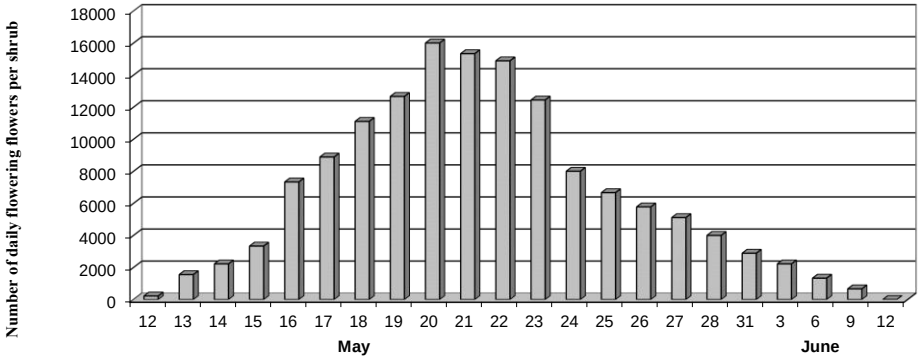

Fig. 2. Flowering abundance of *Weigela florida* in 2007 season (mean of 10 shrubs)

The flowers of *Weigela florida* are clustered in 2-3-flowered cymose inflorescences borne in the leaf axils. The inflorescences were sporadically observed to have only 1 flower. The inflorescence stems were found to blossom most abundantly in the first year of the study. Each of them had from 5 to 9 inflorescences (on average 7.0) (tab. 1). During the full bloom period in this year, there were from 8 to 17 simultaneously open flowers per inflorescence stem and from 1 to 9 newly opened up flowers in each of the successive days of shrub flowering (fig. 3). The flowering rate of inflorescences and inflorescence stems is presented in table 1. In total, from 90 to even 400 flowers were recorded per one running meter of stem (on average 220.2 flowers per 1 meter of stem). One shrub that had from 6 to 10 basal stems (on average 7.8) produced from 10 872 to 48 320 flowers throughout a growing season. The average number of flowers per shrub reached 26 600.

Table 1. Flowering of *Weigela florida* under the conditions of Lublin

Year	Flowering time (days)	Number of flowers per				Length of flower life (days)		Number of days since opening petals to nectar guide color change	
		inflorescence		inflorescence stem					
		mean ±SD	range	mean ±SD	range	mean ±SD	range	mean ±SD	range
2007	12.05–12.06 (32)	2.9 ±0.32^{A}	2–3	7.0 ±1.41^{A}	5–9	6.4 ±0.52^{A}	6–7	3.65 ±0.41^{A}	3–4
2008	12.05–21.06 (41)	2.7 ±0.48^{A}	2–3	6.4 ±0.97^{A}	5–8	6.3 ±0.48^{A}	6–7	3.20 ±0.54^{A}	2.5–4
2009	12.05–28.06 (48)	2.8 ±0.42^{A}	2–3	6.7 ±0.95^{A}	5–8	6.9 ±0.74^{A}	6–8	3.55 ±0.50^{A}	3–4.5
mean	(40.3 ± 8.02)	2.8	–	6.7	–	6.5	–	3.5	–

Means values in column with the same letter are not significantly different at $\alpha \leq 0.05$
SD – standard deviation

Table 2. Mean decade air temperatures and total rainfall during the study period

	Month	2007				2008				2009			
		decade			mean	decade			mean	decade			mean
		I	II	III		I	II	III		I	II	III	
Temperature (°C)	IV	6.21	9.46	10.57	8.70	7.81	9.36	10.78	9.30	11.50	9.30	13.50	11.40
	V	9.94	15.13	19.60	15.00	11.31	13.33	13.59	12.80	13.60	13.10	14.20	13.60
	VI	18.15	20.02	16.19	18.10	17.98	16.37	18.82	17.70	15.30	15.00	19.10	16.40
Precipitation (mm)	IV	8.80	5.60	3.00	17.40	17.60	35.30	2.90	55.80	1.10	1.80	2.90	5.80
	V	13.50	30.90	37.10	81.50	57.10	34.70	9.80	101.60	3.60	34.60	32.90	71.10
	VI	52.40	25.40	10.00	87.80	0.00	19.60	6.30	25.90	28.20	32.70	64.60	125.50

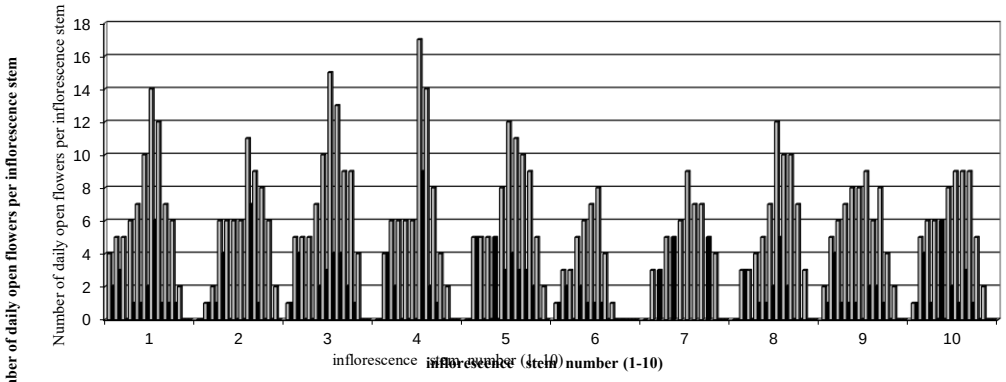

Fig. 3. Flowering dynamics of some inflorescence stem *W. florida* in 2007 season

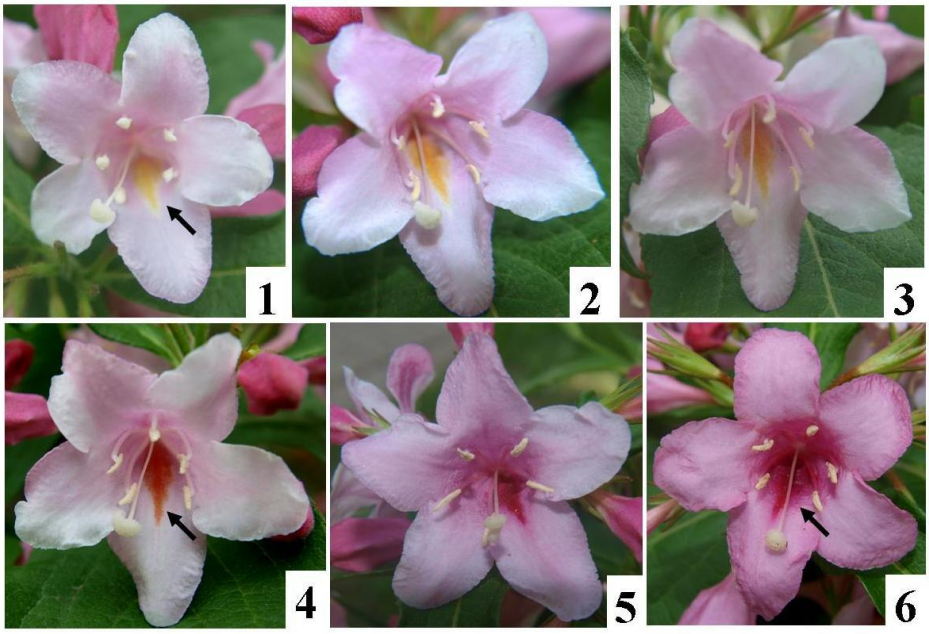

Fig. 4. Flower color change in the successive days of its life in *Weigela florida* (1–6 days of flower life, ← nectar guide)

The flowers of *Weigela florida* are bisexual (fig. 4). Their perianth consists of 5 fused green-colored sepals and 5 bright pink petals fused at the base. The petals form a funnel-shaped floral tube that widens towards the tip of the flower. On the inner side of the longest petal, there is a yellow-orange spot (nectar guide) that extends deep into the throat of the flower and guides insects to the nectar (fig. 4). This nectar guide clearly contrasts with the bright pink color of the petals, which additionally contributes to the

decorative quality of the flower. Five stamens are fused by their filaments to the base of the petals, while the central part comprises one inferior pistil.

The flower life span was similar throughout the study period and it was from 6 to 8 days (on average 6.5 days) (tab. 1). The petal color changed with the age of the flower from white-pink to bright pink and subsequently to dark pink. At the same time, the yellow and then yellow-orange nectar guide in the corolla tube changed its color to red and subsequently to red-carmine (fig. 4). The first changes in the color of the corolla tube and of the nectar guide inside it were observed in hot weather already after 2.5 days from petal opening. Under lower temperature conditions, the color of these flower parts changed as late as 4.5 days after flower opening. After this period, the corolla tube became dark pink, while the nectar guide dark red (tab. 1, fig. 4).

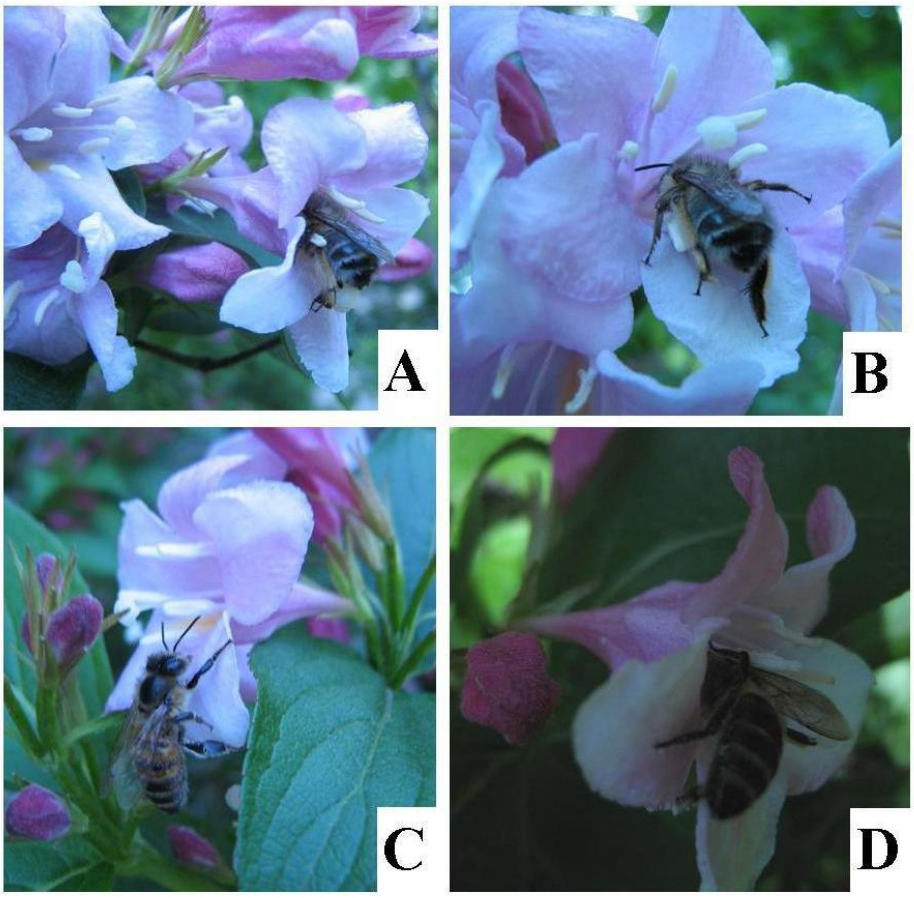

Fig. 5. Bumblebees (A, B) and honeybees (C, D) visiting flowers of *Weigela florida*

Table 3. Dimensios of the flowers *Weigela florida* (cm)

Year		Petal length (A)		Corolla tube length (B)		Corolla lobe length (C)		Flower diameter (D)		Corolla tube diameter at the tube apex (E)	
		mean ±SD	range	mean ±SD	range	mean ±SD	range	mean ±SD	range	mean ±SD	range
2007	I term	3.89 ±0.30^{ab}	3.20–4.20	2.66 ±0.28^{ab}	2.00–2.90	1.23 ±0.09^{ab}	1.10–1.40	3.60 ±0.25^{ab}	3.00–3.80	1.10 ±0.12^{a}	0.90–1.30
	II term	4.09 ±0.18^{a}	3.80–4.30	2.85 ±0.14^{b}	2.60–3.10	1.24 ±0.11^{ab}	1.10–1.40	3.79 ±0.22^{b}	3.50–4.10	1.53 ±0.12^{b}	1.40–1.80
	mean	3.99^{B}	–	2.75^{B}	–	1.23^{A}	–	3.69^{B}	–	1.31^{A}	–
2008	I term	3.63 ±0.33^{b}	3.10–4.20	2.44 ±0.25^{a}	2.00–2.80	1.19 ±0.12^{a}	1.00–1.40	3.48 ±0.20^{ac}	3.20–3.80	1.07 ±0.13^{a}	0.90–1.30
	II term	3.95 ±0.18^{a}	3.70–4.20	2.64 ±0.11^{ab}	2.50–2.80	1.31 ±0.14^{ab}	1.10–1.50	3.52 ±0.17^{abc}	3.30–3.80	1.57 ±0.11^{b}	1.40–1.70
	mean	3.79^{A}	–	2.54^{A}	–	1.25^{A}	–	3.50^{A}	–	1.32^{A}	–
2009	I term	4.00 ±0.16^{a}	3.80–4.30	2.64 ±0.14^{ab}	2.40–2.90	1.36 ±0.13^{b}	1.20–1.60	3.28 ±0.24^{c}	2.90–3.70	1.10 ±0.15^{a}	0.90–1.30
	II term	3.80 ±0.19^{ab}	3.40–4.00	2.54 ±0.13^{a}	2.30–2.70	1.26 ±0.11^{ab}	1.10–1.40	3.63 ±0.16^{ab}	3.40–3.90	1.52 ±0.11^{b}	1.40–1.70
	mean	3.90^{AB}		2.59^{A}		1.31^{A}		3.45^{A}		1.31^{A}	
mean	I term	3.84^{A}	–	2.58^{A}	–	1.26^{A}	–	3.45^{A}	–	1.09^{A}	–
	II term	3.95^{A}	–	2.68^{A}	–	1.27^{A}	–	3.65^{B}	–	1.54^{B}	–
	mean	3.89	–	2.63	–	1.26	–	3.55	–	1.31	–

Means values in column with the same letter are not significantly different at $\alpha \leq 0.05$
SD – standard deviation

The *Weigela florida* flowers differed in their dimensions. During the initial flowering period of the shrubs, the petal length ranged between 3.10 and 4.30 cm, with an average length of 3.84 cm. The average corolla tube length was 2.58 cm during this time, while the corolla lobe length 1.26 cm (tab. 3). At full bloom of the shrubs, the *Weigela florida* flowers reached slightly larger dimensions. The average corolla length was 3.95 cm during this time, including a lobe length of 1.27 cm and a corolla tube length of 2.68 cm. At full flowering stage, the flower dimension was larger than that recorded during the initial phase of this process (tab. 3).

Apoidea, primarily bumblebees, were observed among insects visiting the flowers of *Weigela florida* (fig. 5 A–B). Honey bees visited the flowers in lower numbers (fig. 5 C–D). Both the petal color and the color of the nectar guide had an effect on flower visitation by these pollinating insects. The insects most frequently visited younger (2-3-day-old) flowers at full bloom, with a bright pink color of the petals and a yellow or orange nectar guide in the flower throat, but they avoided older dark pink flowers with a red or red-carmine nectar guide.

Both the bumblebees and honey bees collected the nectar hidden deep at the base of the corolla tube. Having penetrated the flowers, the insects transported pollen grains deposited on their body, mainly on the head, abdomen and back, to the stigma of another flower. The bumblebees sometimes gnawed through the corolla tube at its base and collected the nectar from the flower through the gnawed hole, not participating in the transport of pollen grains in such case. The honey bees almost always visited the flowers in a conventional way, entering the inside of the corolla tube. Sporadically, they collected the nectar through the holes gnawed by the bumblebees. The most intense insect visitation to the shrubs was noticed during late morning hours.

DISCUSSION

In the climatic conditions of Lublin, the flowering of *Weigela florida* Bunge lasts from 4.5 to 7 weeks. The beginning of flowering of the shrubs occurred in the first 10 days of May, while the end of flowering in the second or third 10-day period of June. A similar flowering period for the species in question in Poland is given by Seneta and Dolatowski [2004]. This flowering time is also similar to that reported for *W. florida* in the conditions of other European countries [Howes 1979, Mountain et al. 1981]. Inoue et al. [2007] reports a flowering period of *W. hortensis* under Japanese conditions comparable to that of *Weigela florida*. In Japan Ida and Kudo [2003] found earlier flowering time for *W. middendorffiana* compared to *W. florida*, while Yokoyama et al. [2002] *observed* later flowering time for *W. maximowiczii* compared to *W. florida*.

The shrubs of *Weigela florida* were characterized by scanty inflorescences with 2–3 flowers (on average 2.7). *Weigela hortensis* and hybrids between *W. hortensis* and *W. maximowiczii* produced a similar number of flowers per inflorescence [Yokoyama et al. 2002]. The number of flowers per inflorescence stem changed in the individual growing seasons which differed in weather conditions both in the period preceding flowering and during flowering. Between 6 and 21 flowers (on average 12.4) were recorded on one *W. florida* inflorescence stem [Yokoyama et al. 2002].

Morphological dimensions obtained for *Weigela florida* flowers in the conditions of Lublin, were much higher than described by Seneta and Dolatowski [2004]. However, the above-mentioned authors do not give any detailed morphological measurements of the flower. In their research on the morphology of *W. hortensis* flowers, Inoue et al. [2007] stress that differences in flower size are found even within the same species, which is most frequently attributable to the adaptation of plants to the environment in which they grow and to the adaptation of the morphological characters of flowers to pollination by specific groups of insects. According to Inoue et al. [2007], the average corolla length in *Weigela hortensis* was shorter (3.23 cm) compared to the *Weigela florida* flowers. The corolla tube diameter in *W. hortensis* was also much narrower, since it was only 0.85 cm. The flower dimensions reported by Yokoyama et al. [2002] for *W. hortensis*, *W. maximowiczii* and their interspecific hybrids reach much lower values compared to the species investigated in our study.

The color of the *Weigela florida* flowers changed with their age from bright pink to dark pink, while the color of the nectar guide that directs insects to the nectar from yellow-orange to carmine-red. The results of our observations confirm the opinions of Inoue et al. [2007] and Zhang et al. [2012] who show that the process of flower color change is very common in species of the genus *Weigela*. This *relates* to the color change in both the petals and the nectar guide. In *Weigela japonica* var. *sinica* studied in their research, over a period of 4 days the color of the petals changed from white to red, whereas the color of the nectar guide from yellow to violet. The time of the individual phases was however much shorter than that found in our study for *Weigela florida*, since for the white phase it was 1 day and for the red phase 2 days. At the same time, Zhang et al. [2012] *interpret* the flower color change in *Weigela japonica* var. *sinica* as a mechanism that increases the attractiveness of its flowers to pollinating insects which can see them from a large distance. Niesenbaum et al. [1999] as well as Oberrath and Böhing-Gaese [1999] also confirm that the color of both the petals and nectar guide may influence positively or negatively an insect, encouraging the insect to visit a particular flower or discouraging them from visiting, which also affects plant reproductive success. The results concerning the color change of the nectar guide in the *Weigela florida* flowers are similar to those reported by Ida and Kudo [2003] for *Weigela middendorffiana*. According to the above-mentioned authors, the duration of each phase varied; on average the yellow nectar guide persisted for 3.1 days, whereas the red one for 2.1 days. At the same time, Ida and Kudo [2003] underline that during the yellow nectar guide phase the flowers offered to insects 10 times more nectar and 14 times more pollen compared to older flowers with a red nectar guide. It is the reason foraging preferences.

The results of our observations of insect foraging on the *W. florida* flowers confirm the *opinion of I*da and Kudo [2003] that it can be difficult for insect to notice and identify the nectar guide which is located in the throat of the corolla with fused petals if the insect does not visit the flower from the front.

Howes [1979] also points to the great variation in flower color in species of the genus Weigela and according to this author the flower color ranges from white to crème to different shades of pink and red. Nevertheless, none of the above-mentioned authors

presents the flower's life span, taking into account the successive flower development stages.

Bumblebees and honey bees were insects that visited the flowers of *Weigela florida*. They were observed to be present in greatest numbers during late morning hours. The insects were particularly attracted by bright colored, newly opened flowers on an inflorescence, while they avoided older flowers that had already changed their color to a darker one. The results of our observations obtained for *Weigela florida* are in agreement with those reported by Ida and Kudo [2003], according to whom bumblebees are also the primary pollinators of *Weigela middendorffiana*. The aforementioned authors emphasize that the insects visited younger flowers with a yellow nectar guide much more readily than those with a red nectar guide. Likewise, Inoue et al. [2007] demonstrate that the flowers of *Weigela hortensis are most fre*quently pollinated by 4 bumblebee species. According to these authors, the flowers of *W. hortensis* are perfectly adapted to pollination by bumblebees, which gathered pollen grains on their heads and abdomens. They also collected nectar from the visited flowers. According to Mountain et al. [1981], in England honey bees are the main insects that visit the flowers of *Weigela florida*.

CONCLUSIONS

In the conditions of south-eastern Poland, the flowering of *Weigela florida* lasted from 4.5 to 7 weeks. Full bloom occurred in the 2nd and 3rd weeks of flowering of this species. Single shrubs produced from 10.87 to 48.32 thousand flowers throughout a growing season.

The flowers of *Weigela florida* were visited by bumblebees and honey bees. Flower visitation was mostly observed during late morning hours.

The insects visited young flowers bright pink petals much more readily, while avoiding older flowers being at the later stages of development.

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FENOLOGIA KWITNIENIA *Weigela florida* Bunge I WPŁYW ZMIANY BARWY JEJ KWIATÓW NA BEHAWIORYZM OWADÓW WIZYTUJĄCYCH

Streszczenie. W latach 2007–2009 prowadzono badania nad biologią i obfitością kwitnienia *Weigela florida* Bunge oraz nad wpływem zmiany barwy jej kwiatów na behawioryzm owadów zapylających. W warunkach klimatycznych południowo-wschodniej Polski kwitnienie badanego taksonu rozpoczynało się na początku drugiej dekady maja i trwało od 4,5 do 7 tygodni. Pojedyncze kwiaty *W. florida* żyły średnio 6,5 dnia. Wśród owadów wizytujących kwiaty *Weigela florida* dominowały trzmiele, mniej licznie odwiedzały je

pszczoły miodne. Stwierdzono zróżnicowane zainteresowanie owadów oblotem kwiatów w różnym wieku. Zapylacze częściej odwiedzały kwiaty młode o jasnoróżowej barwie płatków korony z żółtą lub pomarańczową plamką w gardzieli, omijały zaś kwiaty starsze, ciemnoróżowego koloru z czerwoną lub czerwono-karminową plamką wskaźnikową.

Słowa kluczowe: *Weigela*, kwitnienie, zmiana barwy kwiatów, behawioryzm owadów

Accepted for print: 9.02.2016

For citation: Stawiarz, E., Wróblewska, A. (2016). Flowering phenology of *Weigela florida* Bunge and the effect of color change in its flowers on the behavior of visiting insects. Acta Sci. Pol. Hortorum Cultus, 15(3), 45–57.