Morphological Variation of *Erechtites hieracifolia* (L). Raf. ex DC. (Asteraceae) Achenes in the Zone of the Species' Geographic Range Expansion, Based on the Localities from East-Central Europe

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Abstract

Erechtites hieracifolia (L). Raf. ex DC. is a species of American origin that spreads dynamically all over the world as a result of human activity. In the beginning of the 21st century, the number of its localities rapidly increased in Central and Eastern Europe, particularly, in pine forests and degraded peat bogs, where the species grows profusely. It has become an invasive plant and its abundant occurrences are a serious problem in many places. This work shows the results of study on the variation of fruits in *E. hieracifolia*, at the individual, population and interpopulation levels, in the areas of its rapid spread over the pine forests of Poland and Ukraine. It was found that the range of variation at all analysed levels is very similar. However, a small separation of eastern European populations was observed. Also, the production of diaspores was evaluated at maximum 21,000 achenes per an individual.

Key words: forest habitats, invasion, Natura 2000 areas, Poland, Ukraine, variability.

Introduction

Erechtites hieracifolia (L). Raf. ex DC. is an annual plant originating from Northern and Central America (McGregor et al. 1986, Darbyshire et al. 2012). Nowadays, this species can be found in many places all over the world – in Europe (among others, Gaggermeier 1989, Csiszár 2004, Tokarska-Guzik et al. 2009, Krahulec and Hadinec 2011, Orlov and Yakushenko 2011), Asia (among others, Mito and Uesugi 2004, Jung and Chung 2010, Yilin and Nordenstam 2011), New Zealand (Healy 1957) or Hawaii (Wagner et al. 1999). The dynamic spread of *E. hieracifolia* is the consequence of human activity. The species was for the first time noted in Europe in 1876 – in Croatia, in the vicinity of Zagreb. In 1885, it was observed in Austria and next, in the 20th century, in the Czech Republic, Romania and Germany (Górski et al. 2003). The earliest information about the occurrence of *E. hieracifolia* in Poland comes from 1902, from the Lower Silesia region (Schube 1903). Today, the species spreads particularly intensively in south-west and central Poland (Górski et al. 2003, Koczywąs et al. 2012). In Ukraine, *E. hieracifolia* was observed for the first time in 1911 (Csiszár 2004). Presently, it spreads intensively in the north-west part of the country, in the right-bank Polesye (Orlov and Yakushenko 2011).

In the area of its natural range of distribution, *E. hieracifolia* occupies such habitats as, among others, the shores of lakes and pools, floodplains, bogs, fresh and salt marshes, ditches and dune slacks (Darbyshire et al. 2012). In the area of its secondary range, in Central and Eastern Europe, the species prefers forest habitats: wet pine and mixed forests, acidophilous oak forests, clearings and edges of forest roads. Less frequently, it is found in rushes and degraded peat bog vegetation (Wagenitz 1987, Tokarska-Guzik et al. 2009, Orlov and Yakushenko 2011, Koczywąs et al. 2012, Dyderski et al. 2015).

In recent years, *E. hieracifolia*, has been an object of many studies. They concentrated, among others, on the species distribution and expansion (among

others, Csiszár 2004, Orlov and Yakushenko 2011, Koczywąs et al. 2012, Pyšek et al. 2012, Bettinger et al. 2013), chemical compound content (Lorenzo et al. 2001), germination biology (Baskin and Baskin 1996) or ethnobotanical aspects (Srianta et al. 2012). A few varieties of *E. hieracifolia* were distinguished, based on leaf morphology and plant outline (Jung and Chung 2010, Darbyshire et al. 2012). However, no studies of fruit variation in this species in the areas of its dynamic spread were conducted so far. Morphological and anatomical traits of fruits and seeds often provide essential taxonomic information at different taxonomic ranks, like, e.g. in the family Ericaceae (Szkudlarz 1999a, b, 2009) or Asteraceae (Anderberg et al. 2007, Karanović et al. 2016). Based on this premise, the aim of this work was to investigate the morphological characteristics and variability of *E. hieracifolia* achenes at the intraindividual and intra- and interpopulation levels, in populations occurring in two regions of the species' intensive spread: in Wielkopolska (western Poland) and right-bank Polesye (northwest Ukraine), and to estimate the production of diaspores.

Materials and Methods

The research material was collected from herbarium sheets deposited in the Herbarium of Department of Plant Taxonomy, Adam Mickiewicz University in Poznań (POZ) and M.G. Kholodny Institute of Botany, NAS of Ukraine, in Kyiv (KW) (Table 1).

The study of fruit variation in *E. hieracifolia* var. *hieracifolius* was conducted for 3 organizational levels: (1) intraindividual one based on 20 achenes collected from 5 flower heads originating from different parts of one individual, (2) intrapopulation one based on 30 fruits collected from 10 individuals within 1 population, and (3) interpopulation one based on 30 fruits randomly collected from 8 studied populations (Table 1, Figure 1). The number of samples collected for the study of intraindividual variation was restricted to 5 heads and 20 achenes due to the limited availability of inflorescences with mature fruits in the different parts of a shoot. An analysis of achene variability was based on the following morphological traits: length, width, diameter of carpopodium and diameter of the pappus base (Figure 2). The biometric measurements of fruits were made using a calibrated stereo microscope.

Table 1. Collection sites of *Erechtites hieracifolia* achenes

No. of locality	Name of locality	Habitat	Collector (Herbarium)	Date of collection
1	Chlebowo, Wielkopolska region, Poland	Birch-pine forest at the peat bog edge	Z. Celka, P. Szkudlarz (POZ)	13.09.2014
2	Sulmierzyce, Wielkopolska region, Poland	Pine forest	P. Szkudlarz (POZ)	03.10.2014
3	Krajkowo, Wielkopolska region, Poland	Edge of the Warta valley	W. Stachnowicz (POZ)	26.09.2012
4	Zaniemyśl, Wielkopolska region, Poland	Pine forest on a lake shore	W. Żukowski (POZ)	20.10.2013
5	Taczanów, Wielkopolska region, Poland	Clear-cut in mixed forest	Z. Celka, P. Szkudlarz (POZ)	09.10.2014
6	Lygyna, Zhytomyr region, Ukraine	Pine forest	O. O. Orlov (KW)	20.08.2012
7	Makalewyczi, Zhytomyr region, Ukraine	Edge of pine forest and railway track	O. O. Orlov (KW)	20.09.2010
8	Zhovtneve, Zhytomyr region, Ukraine	Peat bog edge	O. O. Orlov (KW)	3.09.2003

Figure 1. Distribution of collection sites of *Erechtites hieracifolia* achenes. Explanations: 1-8 – see Table 1

Figure 2. Schematic illustration of the measured traits of *Erechtites hieracifolia* achene. Explanations: 1. length, 2. width, 3. carpopodium, 4. diameter of pappus base

The obtained results were subject to statistical analysis with software package STATISTICA 10.0 for Windows. This package was used for all standard uni- and multivariate analyses of morphological data.

Results

Achene morphology

A fruit of *E. hieracifolia* is a light brown to dark brown achene. It is long and narrow with 10-12 distinct ribs stretching along the fruit – from its base to

apex (Figure 3). The surface, particularly between the ribs, is covered with widely spaced bristly hairs.

An achene is strongly narrowed in the bottom part that ends with the roundish carpopodium. The upper part of a fruit is also narrowed and bluntly truncated, finished with a disk-shaped base of pappus. The pappus consists of numerous, long and single hairs. Their length ranges from 9.35-16.15 mm, with an average of 13.12 mm (Figure 4). The pappus easily comes off an achene, leaving a white, disk-shaped base around the fruit edge.

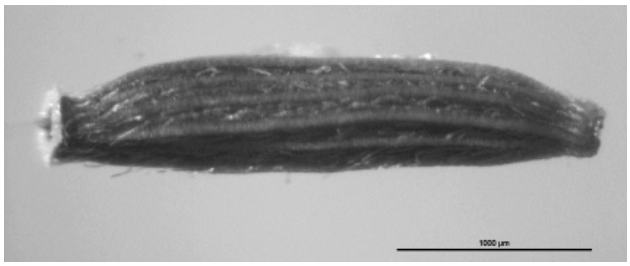

Figure 3. Achene of *Erechites hieracifolia* from the locality in Chlebowo (Photo by P. Szkudlarz, 2015)

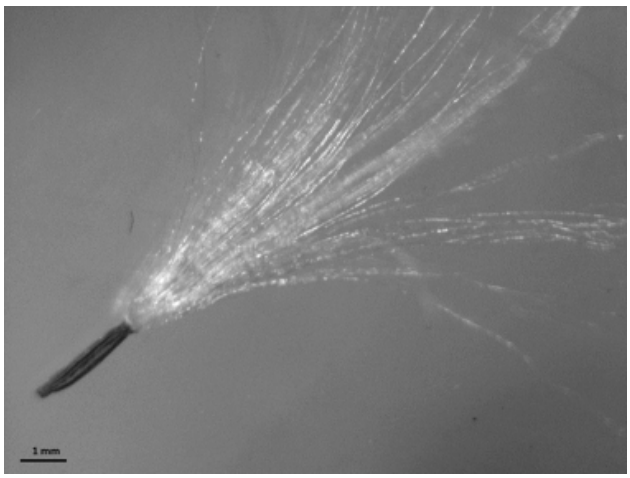

Figure 4. Achene of *Erechites hieracifolia* with the pappus, collected in the locality in Taczanów (Photo by P. Szkudlarz 2015)

Productivity of diaspores

The inflorescences of *E. hieracifolia* develop gradually, starting from top flower heads on a main stem and top flower heads on lateral stems. Also, fruits mature in a similar sequence and, then, fall apart, before lower heads mature.

The obtained results showed that smaller individuals (up to 1 m in height) produce up to 50 flower heads on average, while larger individuals (above 1 m in height) – about 120 inflorescences on average. It was observed that a single individual contains a different number of achenes, depending on the location of a head within a plant. A subapical lateral head comprises 235 achenes, a head situated on a upper lateral stem – 190, while situated on a lower lateral stem – 155. One inflorescence produces on average about 180 fruits. Estimate calculations based on the obtained results show that a single individual, depending on its size, produces from 9,000 to over 21,000 achenes.

Intraindividual achene variation

To determine an intraindividual variation of achenes, a herbarium specimen of *E. hieracifolia* with numerous flower heads was selected. Next, those inflorescences that had mature fruits located at different branches were collected for the study. The conducted analysis showed that the achene length ranges from 2.6 to 3.3 mm and width from 0.48 to 0.80 mm, while the diameter of carpopodium ranges from 0.19 to 0.31 mm and of pappus base from 0.39 to 0.55 mm. The obtained results show that the differences between the fruits from flower heads of single individual are small (Figure 5).

Intrapopulation achene variation

The length of achenes ranges from 1.88 to 2.54 mm, and width from 0.35 to 0.48 mm, the diameter of carpopodium ranges from 0.11 to 0.40 mm, and the diameter of the pappus base from 0.03 to 0.29 mm. The average achene length is 2.56 mm and width is 0.59 mm; the average diameter of carpopodium is 0.22 mm, and the diameter of the pappus base is 0.36 mm (Figure 6). The intrapopulation investigations indicate only small differences between individuals. The typical values overlap.

Interpopulation achene variation

Investigations conducted at the interpopulation level, comprising both the Polish and Ukrainian populations, showed the achene length within all studied populations ranges from nearly 2 to 3 mm, while width from 0.40 to 0.77 mm. The diameter of carpopodium varies from 0.18 to 0.40 mm, while the diameter of pappus base from 0.24 to 0.51 mm (Figure 7).

The conducted interpopulation analysis shows some separation between Ukrainian and Polish populations. Although the variation range of Ukrainian populations almost completely overlaps with the variation of Polish samples, the mean values of the former are distinctly shifted relative to the mean values of all analysed traits in the Polish populations. This separation has been revealed by the results of PCA analysis

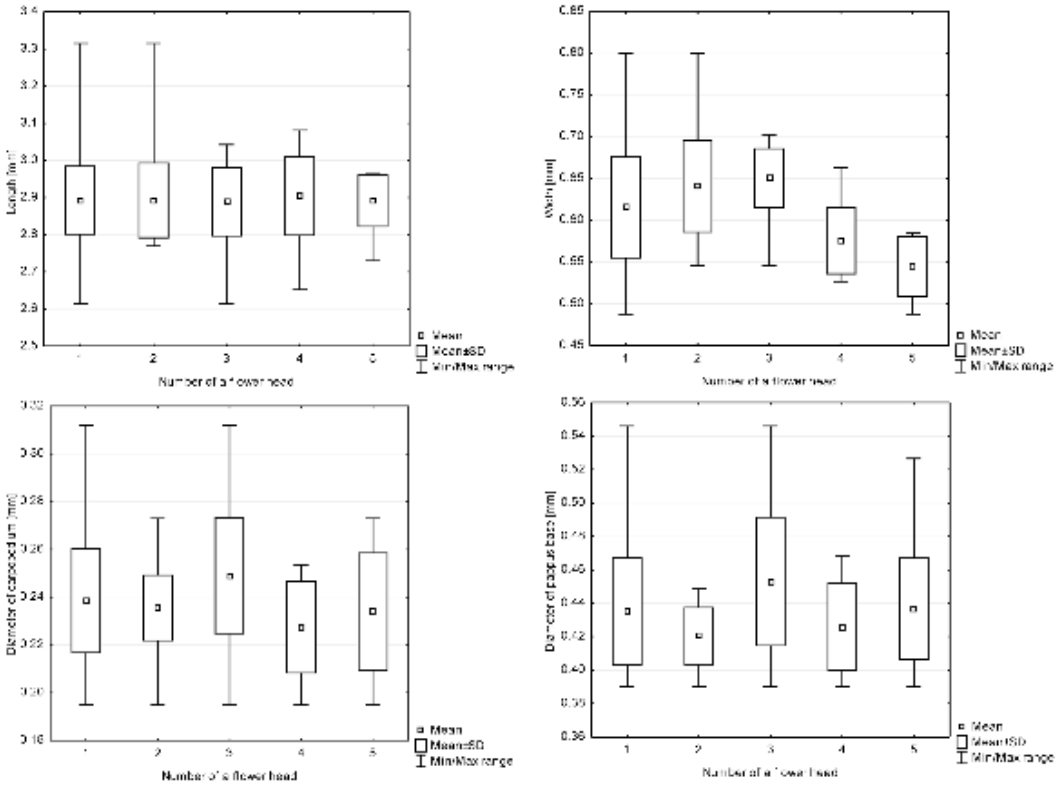

Figure 5. Intraindividual variation of morphological characters of *Erechtites hieracifolia* achenes

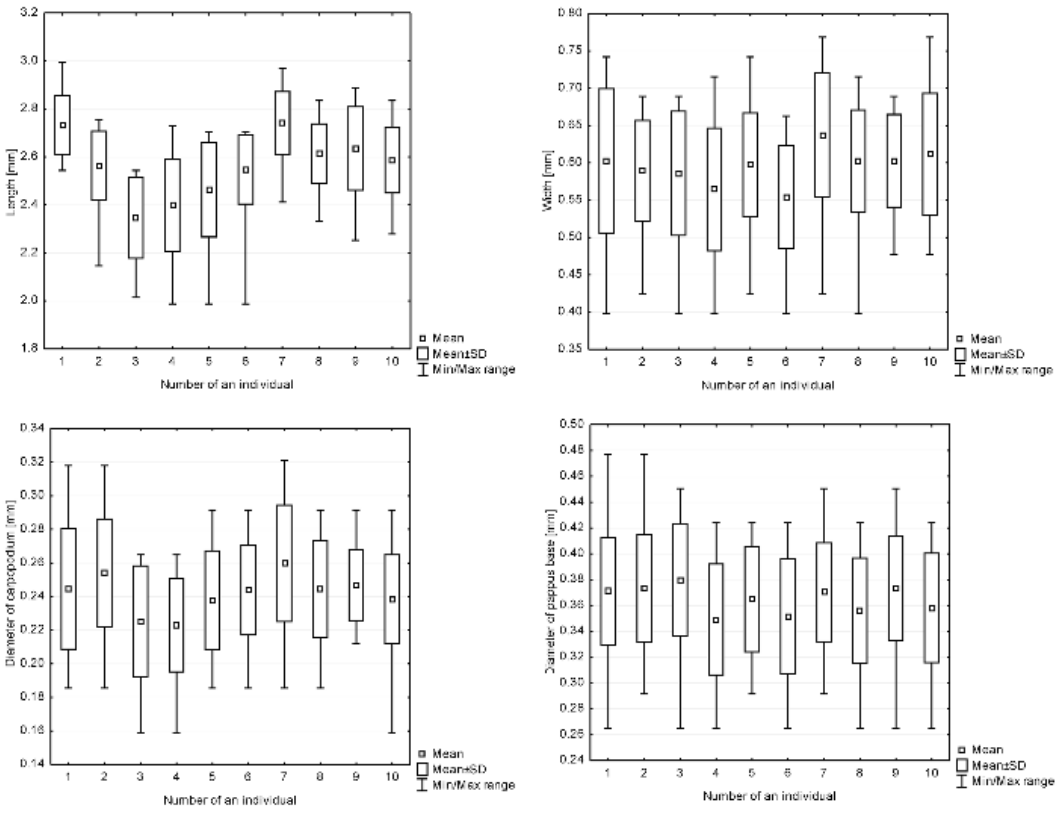

Figure 6. Intrapopulation variation of morphological characters of *Erechtites hieracifolia* achenes

(Figure 8). The obtained distribution is mainly affected by the PCA1 component correlated with the achene width and diameter of pappus base. The PCA1 and PCA2 components explain over 72% of total variation. Populations 6, 7 and 8 form a group, in which individuals have positive PCA1 values, while the remaining populations (1-5) are dispersed in the central and left side of the diagram and have negative PCA1 values.

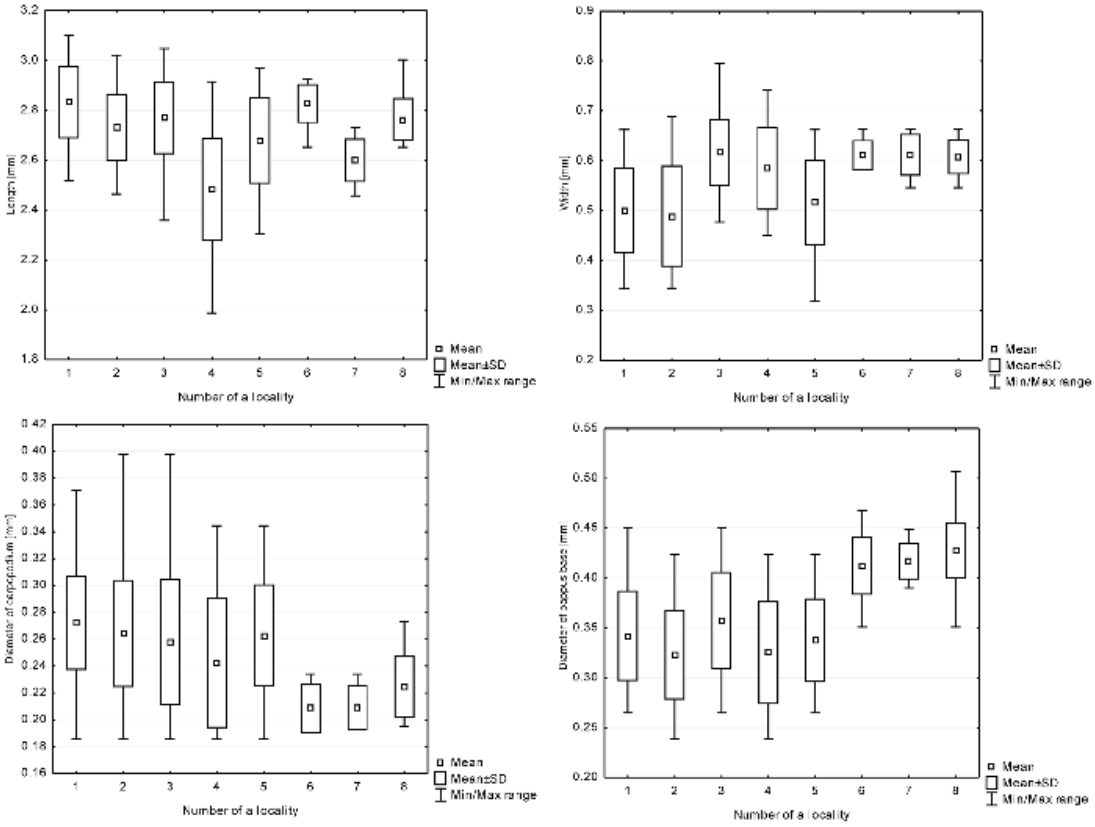

Figure 7. Interpopulation variation of morphological characters of *Erechtites hieracifolia* achenes (the number of locality cf. Table 1)

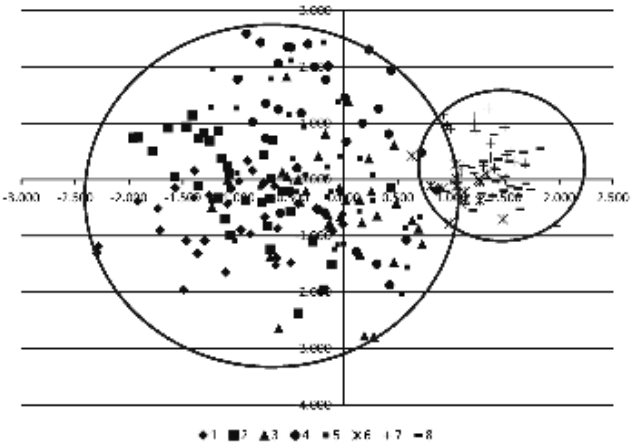

Figure 8. Principal component analysis. Explanations: 1-8 – the number of locality (cf. Table 1)

Discussion

A fruit in the family Asteraceae is a dry, indehiscent achene (Wagenitz 1987, Anderberg et al. 2007). The morphological traits of achenes are considered to be useful in the taxonomic studies of Asteraceae. They are particularly useful in the diagnostics of some tribes, e.g. such as: Astereae (Talukdar 2015), Cardueae (Mukherjee and Talukdar 2013), Cichoreae (Abid and Qaiser 2015) and Heliantheae (Talukdar and Mukherjee 2014), as well as the genera like *Achillea* (Akcin and Akcin 2014), *Anacyclus* (Torices et al. 2013), *Anthemis* (Chehregani and Mahanfar 2007) and *Carthamus* (Hacıoğlu et al. 2012).

An interspecific variation in Asteraceae was investigated in *Lactuca seriolla* (Křístková et al. 2014). In this species, the correlation between the achene length and geographic latitude was observed. The samples from the plants growing approximately at the same latitude

did not show such correlation. Similar relationships were observed in other taxonomic groups, e.g. seed variation related to a geographic gradient in *Loiseleuria procumbens* from Ericaceae (Szkudlarz 2003).

No studies of achene morphological variation in *E. hieracifolia* were conducted so far. Thus, a very limited amount of literature data makes the discussion of our results of achene variation difficult. However, the length of analysed achenes falls into the range of lengths cited in literature (Bojňanský and Fargašová 2007, Darbyshire et al. 2012), while the width has a slightly higher range of variation (Bojňanský and Fargašová 2007). A comparison of the range of achene variation obtained in this study with other species of Asteraceae (*Lactuca* L., *Senecio* L.) shows that the percentage range is comparable (Mukherjee 2001, Hacıoğlu 2012, Křístková et al. 2014). It is worth stressing that the ranges of variation and coefficients of variation, both at the intraindividual and intra- and interpopulation level, are very similar – the coefficient of variation at each studied organizational level is lower than 10%. A relatively low level of variation of *E. hieracifolia* in East-Central Europe can be compared to a low variation of another expansive species – *Anthoxanthum aristatum* Boiss. (Poaceae), which currently spreads in Western and Central Europe (Drapikowska 2013). A low variation of the latter may result from the fact that only some part of gene pool of *A. aristatum* spreads beyond the species of original range of distribution (Drapikowska 2013).

Analysis of this study results at the interpopulation level showed that despite general similarity, the examined populations can be divided into two groups – Polish and Ukrainian ones. Although the variation range of each studied trait of Ukrainian populations overlaps with the variation range of Polish samples, the mean values for Ukrainian populations are distinctly shifted in relation to the mean values of all analysed traits of Polish populations. This separation is shown by the PCA analysis (cf. Figure 8). The obtained result is important, because it may indicate some geographic differentiation of populations, which may result from microevolutionary processes in newly colonized areas (see Křístková et al. 2014).

Also, the number of fruits produced by *E. hieracifolia* was determined during the study. The productivity of diaspores is of high importance in the forecasting the degree of threat that a given species may pose. Thus, the determination of the number of flower heads and fruits is essential, especially, when literature data are underestimated (cf. Wagenitz 1987). The conducted observations are also important for finding the causes and rate of spread of *E. hieracifolia*, which is considered an invasive species in Poland. It invades plant communities occurring in anthropogenic, semi-natural and natural habitats (Tokarska-Guzik et al. 2012). The species occurs also within the Natura 2000 areas, e.g. PLB180005 "Puszcza Sandomierska" or PLH300016 "Bagno Chlebowo". In additon, it invades the Natura 2000 habitat of *Luzulo luzuloides-Fagetum* (Du Rietz 1923) Markgraf 1932 beech forests (kod 9110) (Tokarska-Guzik et al. 2009, 2012; Paul 2013) and potentially poses a threat to some species listed in the Annex II of Habitat Directive, e.g. to *Eleocharis carniolica* W.D.J. Koch (Paul 2013). Also, in Ukraine, it is considered to be a forest weed, recently very expansive, particularly, in forest areas (Orlov and Yakushenko 2011).

Conclusion

The obtained results show that the length of analyzed achenes of *E. hieracifolia* falls into the range of lengths cited in literature, while the width has a slightly wider range of values. The variation ranges of the studied traits at the intraindividual and intra- and interpopulation levels are very similar. At the intrapopulation level, the separation of two groups of populations, i.e. from central and eastern Europe, was noted. Also, it was found that *E. hieracifolia* produces a high number of diaspores – maximally 21,000 of achenes per an individual.

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