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DATA PAPER

GERMINATION CAPACITY OF 75 HERBACEOUS SPECIES OF THE PANNONIAN FLORA AND IMPLICATIONS FOR RESTORATION

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Seeds ensure the survival and dispersal of the majority of vascular plant species. Seeds require species-specific germination conditions and display very different germination capacities using different germination methods. Despite the importance of plant generative reproduction, little is known about the germination capacity of the seeds of the Pannonian flora, particularly under field conditions. Our aim was to reduce this knowledge gap by providing original data on the germination capacity of 75 herbaceous species. We reported the germination capacity of 8 species for the first time. We also highlighted the year-to-year differences in the germination capacity of 11 species which could be highly variable between years. The data regarding the germination capacity of target species, as well as weeds and invasive species, can be informative for nature conservation and restoration projects. Our findings support the composition of proper seed mixtures for ecological restoration and also highlight the importance of testing seed germination capacity before sowing.

Key words: database, germination potential, germination rate, grassland restoration, regional flora

INTRODUCTION

Seeds are crucial in the reproduction and dispersal of plant species, and are important components of community resilience. Viable seeds germinate immediately after seed maturation or enter to a dormant state, which can last from a few days to years, forming a transient or persistent seed bank (Baskin and Baskin 1998, Molnár V. *et al.* 2015). Dormancy of seeds represents a way of bridging unfavourable conditions, enabling seeds to germinate only when all environmental conditions seem suitable for seedling survival (Valkó *et al.* 2014). In this way species and communities can survive unexpected events and unfavourable environmental conditions, such as fire, flood events or drought (Akinola *et al.* 1998, Bossuyt and Honnay 2008, Kimura and Tsuyuzaki 2011).

At the end of the dormant state, active metabolism is resumed and the seed germinates (Kozlowski 2012). To achieve germination, sufficient moisture supply, suitable temperature and proper aeration of the soil are crucial (Kozlowski 2012), although some species may have specific requirements (Baskin and Baskin 1998). For example, hard-coated seeds often require scarification or stratification in order to break their dormancy (Endrédi 2012, Endrédi *et al.* 2012, Lovas-Kiss *et al.* 2015, Patanè and Gresta 2006, Valkó *et al.* 2018). In the case of plants used in agriculture the International Seed Testing Association (ISTA) provides information about species specific requirements (ISTA 2018). Baskin and Baskin (1998) collected data from germination studies and formulated suggestions for future experiments. They suggested using seeds shortly after harvesting, otherwise their germination capacity can change during storage, or they can enter dormancy. If possible, factors such as water permeability should be tested, to check whether seeds can take in water and whether they are able to germinate. Optimal storage conditions are crucial to preserve seeds (Budelsky and Galatowitsch 1999). Baskin and Baskin (1998) also provided information on inducing germination and increasing germination rates for some species, and highlighted that several factors, such as temperature, moisture or salinity have to be tested to identify the most appropriate conditions (Covell *et al.* 1986, Gulzar and Khan 2001, Huang *et al.* 2003, Roberts 1988). To maximise germination rates, the most suitable germination method has to be identified (Peti *et al.* 2017).

Given that germination conditions are very species-specific, and testing germination is labour-intensive, data on the germination capacity of species are scarce. Germination capacity has mostly been studied for agricultural crops, as well as garden and ornamental plants (ISTA). In spite of the increasing involvement of seed traits in ecological research (Hintze *et al.* 2013, Kelemen *et al.* 2015, 2016, Török *et al.* 2013, 2016), we only found two databases, which contained information about the seed germination capacity of the wild plant species of the Central European flora (SID – RBGK 2018, HUSEED^{wild} – Peti *et al.* 2017). The large international plant trait databases lack such information (LEDA – Kleyer *et al.* 2008, D^3 – Hintze *et al.* 2013). Although many restoration experiments were conducted with seed sowing in Hungary (Deák *et al.* 2011, Török *et al.* 2010, 2011, Valkó *et al.* 2016), local data on germination capacity were hardly available for the Pannonian flora until recent times. The first germination percentage data of 744 taxa collected in Hungary were published online in the HUSEED^{wild} database (Peti *et al.* 2017, hereafter HUSEED). This database contains information about the germination capacity of seeds of the Pannonian flora under laboratory conditions, using wetted filter-paper as a germination substrate. They aimed at maximizing germination success so they tested multiple germination methods. In the database, they provided germination capacity data for the most successful germination method. Germination data was also published for *Salvia* (Nyárádi-Szabady *et al.* 1992) and *Erysimum* species (Csontos *et al.* 2010), and for rare and protected herbs such as *Vicia biennis* (Endrédi 2012, Endrédi *et al.* 2012), *Trifolium vesiculosum* (Endrédi 2012) and *Astragalus contortuplicatus* (Lovas-Kiss *et al.* 2015, Molnár V. *et al*. 2015) and the recently discovered alien *Cochlearia danica* (Fekete *et al.* 2018). Kövendi-Jakó *et al.* (2016) published germination records for 12 dry grassland species.

However, data on the germination capacity of the Pannonian flora under near-natural conditions are still scarce. Knowledge of the germination capacity of the regional flora would not only be useful in germination experiments, but would also provide information for restoration projects. By studying germination capacity of seeds, we should answer questions such as how a community would regenerate after a disturbance, or which species could be used for restoration purposes. Our aim was to provide data regarding the germination capacity of herbaceous species of the Hungarian flora under near-natural controlled conditions. Among the analysed species there were target species of ecological restoration projects and also weeds and invasive species that can pose problems for nature conservation. We also tested the year-to-year variability of the germination capacity of 20 species collected from the same populations in three consecutive years.

MATERIALS AND METHODS

Seeds were collected in the Carpathian Basin between 2006 and 2017 (for locations and dates, see Tables 1 and 2). Most of the seeds originated from the Great Hungarian Plain. One species (*Erophila verna*) was collected in Romania. Seeds were collected after maturation (Tables 1 and 2) and dry-stored until the germination experiments. In the case of five short-lived Brassicaceae species a long time period elapsed between their collection and germination (Miglécz *et al.* 2013), but they are known for their long-lived seeds so the longer time period had no effect on their germination capacity. In the case of the other 70 species, seeds were germinated in the year of collection or in the following year (details given in Tables 1 and 2). Before germination, seeds were cleaned, and only intact seeds were used in the experiments. We used 8 cm × 8 cm × 12 cm pots, filled with potting soil. We placed 25, 50 or 100 seeds on each pot. The pots were ordered randomly and placed under natural light in room temperature, or were placed in unheated greenhouses. The number of seeds per pot,

Table 1

Collection date and location, sowing date and number of sown seeds and germination capacity of 55 species of the Hungarian flora. Data from HUSEED (Peti *et al.* 2017) and SID (RBGK 2018) databases are given for comparison. For the original data on germination capacity, we report mean±SD. In case of data from HUSEED and SID databases, we report mean±SD values, where it was possible, and mean values in all other cases. For data from HUSEED and SID databases, asterisks denote that some kind of treatment (chemical treatments, stratification, scarification or hydratation) was applied prior to germination. Germination conditions: indoor germination on germination shelves, natural light, regular watering with tap water, room temperature for sowing in 23.03.2011 (Miglécz *et al.* 2013), 29.04.2013 (Sonkoly *et al.* 2017), and 25.10.2014; greenhouse, natural light, regular watering with tap water for all other cases. No. seeds gives the number of seeds sown per pot, and the number of replicates in brackets

Species	Collection		Sowing		Germination capacity (%)		
	Date	Location	Date	No. seeds	Original data	HUSEED	SID
Agrimonia eupatoria	06.09.2017	Nagyiván	12.09.2017	25(5)	6.4±4.6	63.3±8.4*	58.0±6.8*
Agrostis stolonifera	12.07.2012	Hortobágy	29.04.2013	100(3)	16.0±6.1	30.0	92.2±15.0*
Alopecurus geniculatus	13.06.2013	Egyek	24.03.2014	50(5)	36.4±18.4	2.0	91.0 ±2.8
Ambrosia artemisiifolia	15.09.2016	Debrecen	05.04.2017	25(5)	61.6±12.2	NA	NA
Arabidopsis thaliana	14.05.2009	Nádudvar	23.03.2011	100(5)	68.2±26.4	79.0*	88.1±14.9
Arctium lappa	22.08.2017	Nádudvar	12.09.2017	25(5)	80.0±11.3	90.0*	98.6±2.2
Asclepias syriaca	15.09.2016	Debrecen	05.04.2017	25(5)	33.6±20.7	NA	NA
Aster tripolium subsp. *pannonicum*	01.10.2012	Hortobágy	29.04.2013	100(3)	21.0±10.8	66.7±12.2	NA
Beckmannia eruciformis	01.10.2012	Hortobágy	29.04.2013	100(3)	4.7±3.8	16.0*	89.6±12.4*
Bromus inermis	11.07.2016	Egyek	05.04.2017	25(5)	85.6±5.4	89.6±6.4*	NA
Bromus sterilis	11.07.2017	Egyek	12.09.2017	25(5)	66.4±11.5	84.0*	85.3±17.3*
Bromus tectorum	11.07.2017	Egyek	12.09.2017	25(5)	98.4±3.6	97.0*	96.0±6.3*
Capsella bursa-pastoris	13.05.2009	Nádudvar	23.03.2011	100(5)	60.2±18.9	69.5*	94.8±6.9*
Centaurea solstitialis	12.09.2016	Karcag	05.04.2017	25(5)	91.2±5.2	NA	75.0
Cirsium arvense	11.07.2016	Egyek	05.04.2017	25(5)	36.8±15.6	12.0*	96.0±4.6

Table 1 (continued)

Species	Collection		Sowing		Germination capacity (%)		
	Date	Location	Date	No. seeds	Original data	HUSEED	SID
Conyza canadensis	01.08.2016	Püspökladány	05.04.2017	25(5)	76.0±7.5	NA	NA
Cruciata pedemontana	13.06.2017	Püspökladány	12.09.2017	25(5)	84.8±7.7	93.0*	NA
Cynodon dactylon	27.07.2016	Debrecen	05.04.2017	25(5)	11.2±5.9	100.0*	87.4±9.9*
Cynoglossum officinale	05.08.2017	Hajdúszoboszló	12.09.2017	25(5)	41.6±15.4	51.0*	88.3±14.7*
Daucus carota	16.09.2017	Nádudvar	12.09.2017	25(5)	7.2±8.2	63.0*	82.4±12.9
Descurainia sophia	10.07.2007	Egyek	23.03.2011	100(5)	78.4±3.6	19.0*	NA
Erophila verna	24.04.2010	Magyarszovát	23.03.2011	100(5)	31.8±6.8	22.4*	NA
Festuca pseudovina	16.06.2014	Tiszafüred	25.10.2014	100(3)	97.6±5.5	94.0	100.0
Geum urbanum	29.07.2017	Balmazújváros	12.09.2017	25(5)	73.6±19.3	59.0 ± 3.4*	93.6±7.8
Gypsophila muralis	09.07.2013	Püspökladány	24.03.2014	50(5)	69.2±12.0	NA	NA
Hordeum hystrix	16.07.2013	Balmazújváros	24.03.2014	50(5)	74.0±18.3	95.0 *	NA
Hordeum jubatum	05.09.2012	Balmazújváros	29.04.2013	100(3)	69.7±6.8	NA	90.0*
Hordeum murinum	05.09.2017	Méntelek	12.09.2017	25(5)	100.0±0.0	97.0 *	98.0±2.9*
Juncus compressus	04.07.2013	Balmazújváros	24.03.2014	50(5)	45.2±14.0	33.5*	87.5±13.4
Juncus gerardii	02.07.2013	Tiszafüred	24.03.2014	50(5)	8.4±5.9	0.5.0 *	96.0
Lactuca serriola	17.08.2016	Egyek	05.04.2017	25(5)	76.0±18.5	98.0 *	94.1±8.5
Lepidium campestre	26.06.2008	Cserépfalu	23.03.2011	100(5)	74.6±20.8	78.5*	NA
Lepidium cartilagineum	15.07.2013	Fülöpszállás	24.03.2014	50(5)	75.6±0.9	74.0 *	NA
Lepidium perfoliatum	02.07.2013	Tiszafüred	24.03.2014	50(5)	51.2±13.5	71.3±11.6*	NA
Lepidium ruderale	02.07.2013	Tiszafüred	24.03.2014	50(5)	42.4±15.6	38.0 *	85.6±12.7
Lythrum hyssopifolia	13.07.2013	Hortobágy	24.03.2014	50(5)	14.8±10.0	NA	76.8±13.5*

Table 1 (continued)

Species	Collection		Sowing		Germination capacity (%)		
	Date	Location	Date	No. seeds	Original data	HUSEED	SID
Melica transsilvanica	30.08.2017	Ágasegyháza	12.09.2017	25(5)	86.4±7.3	93.2 ± 3.1*	NA
Myosurus minimus	17.07.2013	Hortobágy	24.03.2014	50(5)	55.2±5.4	NA	88.6±14.7*
Pholiurus pannonicus	02.07.2013	Tiszafüred	24.03.2014	50(5)	6.08±2.3	NA	60.0±5.7*
Physocaulis nodosus	04.07.2017	Debrecen	12.09.2017	25(5)	93.6±4.6	NA	NA
Plantago maritima	18.07.2013	Gyula	24.03.2014	50(5)	76.0±8.6	49.0 *	89.6±13.3
Plantago schwarzenbergiana	18.07.2013	Gyula	24.03.2014	50(5)	85.6±5.4	67.5	NA
Plantago tenuiflora	02.07.2013	Tiszafüred	24.03.2014	50(5)	67.2±10.8	NA	99.0 ±1.4
Podospermum canum	02.07.2013	Tiszafüred	24.03.2014	50(5)	36.0±13.0	NA	78.0 ±17.0
Puccinellia limosa	02.07.2013	Tiszafüred	24.03.2014	50(5)	58.4±7.0	14.0 *	NA
Pulicaria vulgaris	17.07.2013	Hortobágy	24.03.2014	50(5)	54.4±10.1	NA	98.5±3.0
Ranunculus sardous	17.07.2013	Hortobágy	24.03.2014	50(5)	7.6±6.2	48.0 ± 12.6*	88.5±7.7
Rorippa sylvestris subsp. *kerneri*	13.06.2013	Egyek	24.03.2014	50(5)	50.4±13.7	16.0 *	NA
Secale sylvestre	24.07.2017	Méntelek	12.09.2017	25(5)	64.0±8.5	28.0 *	84.5±13.6*
Solidago canadensis	15.09.2016	Debrecen	05.04.2017	25(5)	60.8±11.1	NA	78.3±13.0
Spergularia maritima	04.07.2013	Balmazújváros	24.03.2014	50(5)	56.0±5.7	NA	NA
Torilis arvensis	11.07.2017	Egyek	12.09.2017	25(5)	87.2±7.7	84.5*	79.3±19.3
Tragopogon dubius	05.07.2016	Debrecen	05.04.2017	25(5)	82.4±8.3	85.0 ± 1.5	97.2±6.9
Tragus racemosus	26.08.2017	Debrecen	12.09.2017	25(5)	3.2±5.2	NA	NA
Trifolium fragriferum	17.07.2013	Hortobágy	24.03.2014	50(5)	4.0±3.2	16.0 *	94.3±8.7*
Trifolium repens	18.07.2013	Gyula	24.03.2014	50(5)	3.6±2.6	79.0 *	91.1±11.0*
Trifolium strictum	02.07.2013	Egyek	24.03.2014	50(5)	1.6±1.7	NA	99.0±1.4*

Table 2

Source populations, date of collection, and germination capacity (%, mean±SD) of 20 species of the Hungarian flora. Sowing conditions: 100 seeds in 3 replicates sown in 28 October 2014 (Year 1), 28 October 2015 (Year 2) and 19 October 2016 (Year 3). Germination conditions: indoor germination on germination shelves, natural light, regular watering with tap water, room temperature. Significant differences in germination capacity between years are marked with bold (one-way ANOVA and Tukey test, $p < 0.05$). Data from HUSEED (Peti *et al.* 2017) and SID (RBGK 2018) databases are given for comparison. In case of data from HUSEED and SID databases, we reported mean±SD values, where it was possible, and mean values in all other cases. For data from HUSEED and SID databases, asterisks denote that some kind of treatment (chemical treatments, stratification, scarification or hydratation) was applied prior to germination

Species	Source population	Collection date			Germination capacity (%)			HUSEED	SID
		Year 1 (2014)	Year 2 (2015)	Year 3 (2016)	Year 1	Year 2	Year 3		
Achillea collina	Karcag	17.09.	16.09.	25.08.	**80.6±6.0**^{a}	**50.3±7.4**^{b}	**66.3±9.5**^{ab}	83.5	NA
Centaurea jacea subsp. *angustifolia*	Egyek	03.09.	17.09.	26.08.	**23.0±4.0**^{a}	**23.7±8.5**^{a}	**50.0±7.0**^{b}	79.7±3.2*	81.3±20.6
Cruciata pedemontana	Püspökladány	23.05.	24.06.	09.06.	**49.6±24.5**^{a}	**99.3±1.2**^{b}	**91.3±3.1**^{b}	93.0*	NA
Dianthus pontederae	Egyek	13.06.	16.07.	07.06.	73.0±14.4	87.7±0.6	74.7±10.6	83.0±7.6	100.0±0.0
Falcaria vulgaris	Törökszentmiklós	06.09.	16.09.	28.08.	**15.0±7.0**^{a}	**36.7±3.8**^{b}	**30.7±5.0**^{b}	6.0*	87.7±6.4
Filipendula vulgaris	Legyesbénye	15.07.	19.07.	29.07.	**61.6±7.1**^{a}	**84.3±4.6**^{b}	**25.3±5.5**^{c}	37.0±4.7	98.2±3.5
Galium verum	Karcag	13.08.	16.09.	25.08.	59.3±6.4	71.7±10.5	78.3±4.7	66.0±7.2*	78.1±15.0
Hypericum perforatum	Hortobágy	30.09.	23.09.	24.08.	**41.6±3.5**^{ab}	**33.0±1.7**^{a}	**52.3±11.5**^{b}	40.3±6.2*	83.5±15.5
Knautia arvensis	Debrecen-Józsa	30.09.	23.09.	24.08.	52.3±3.2	55.0±2.7	55.0±3.6	0.0*	NA
Lotus corniculatus	Hortobágy	14.08.	05.08.	29.07.	21.6±5.7	14.3±6.0	11.3±1.5	57.3±17.1*	98.2±2.9*
Lycopsis arvensis	Tiszafüred	22.07.	03.08.	30.08.	**11.6±2.9**^{a}	**51.0±10.5**^{b}	**5.7±2.3**^{a}	NA	NA
Plantago media	Legyesbénye	15.07.	19.07.	29.07.	44.6±11.9	49.0±5.3	45.7±4.7	81.3±3.2	97.0
Podospermum canum	Karcag	19.05.	20.05.	22.05.	83.0±8.9	90.0±1.7	81.3±6.0	NA	78.0±17.0
Rapistrum perenne	Hajdúszoboszló	22.07.	03.08.	31.07.	**0.6±0.6**^{a}	**12.3±3.2**^{b}	**4.7±4.0**^{a}	0.0*	63.5±19.1*

Table 2 (continued)

Species	Source population	Collection date			Germination capacity (%)			HUSEED	SID
		Year 1 (2014)	Year 2 (2015)	Year 3 (2016)	Year 1	Year 2	Year 3		
Salvia austriaca	Egyek	03.06.	04.06.	02.07.	**35.0±10.5**^{a}	**80.3±6.8**^{b}	**70.3±4.5**^{b}	18.0	NA
Salvia nemorosa	Egyek	13.06.	16.07.	02.07.	**18.3±0.6**^{a}	**37.7±3.1**^{b}	**0.0±0.0**^{c}	11.8±7.6*	93.8±7.5
Scabiosa ochroleuca	Nagymacs	22.08.	23.09.	24.08.	44.6±58.2	66.7±11.6	54.7±6.6	42.0*	96.0
Securigera varia	Legyesbénye	15.07.	19.07.	29.07.	14.6±8.0	16.7±3.8	9.7±3.2	NA	87.5±16.2*
Silene viscosa	Egyek	13.06.	16.07.	23.06.	78.0±26.9	60.0±12.0	87.0±3.0	93.0	NA
Thymus glabrescens	Egyek	13.06.	16.07.	01.08.	**72.3±16.4**^{a}	**75.7±1.5**^{a}	**13.0±10.8**^{b}	56.0	NA

the number of replicates and germination conditions are indicated for each species in Tables 1 and 2. The pots were watered with tap water regularly. Seedlings were counted and removed at weekly intervals. Nomenclature follows Király (2009).

To study the year-to-year variation of the germination capacity of 20 common species of dry grasslands, we collected seeds in the same populations in three consecutive years (Table 2). The yearly variation of the seed germination capacity of 20 species in three consecutive years was tested using one-way ANOVA and Tukey's tests in R.

RESULTS

We provided data on the germination capacity of 75 species under controlled conditions, at room temperature or in a greenhouse. We reported the germination capacity of 20 species not included in HUSEED and 26 not included in SID, of which 8 species were new to both databases. The mean and standard deviation of the germination capacity found in our study is shown in Table 1, and, as comparison, mean scores from HUSEED and SID databases are also given. The lowest germination capacities – below 5% – were observed for legumes, such as *Trifolium strictum* (1.6%), *Trifolium repens* (3.6%), *Trifolium fragiferum* (4.0%) and grasses, such as *Tragus racemosus* (3.2%) and *Beckmannia eruciformis* (4.7%). The highest germination capacities were recorded for grasses (*Festuca pseudovina*, *Bromus tectorum* and *Hordeum murinum*) reaching 97.6%, 98.4% and 100%, respectively.

Year-to-year differences in the germination capacity of 20 dry grassland species are shown in Table 2. There were significant yearly differences in the germination capacity of 11 species. *Rapistrum perenne* had the lowest mean germination capacity (5.9%), having a maximum germination capacity of 12.3%. Hard-seeded species, such as *Securigera varia*, *Lotus corniculatus* and *Salvia nemorosa* also had a mean germination capacity below 20%; *Salvia nemorosa* showed significant differences between years. *Cruciata pedemontana* and *Podospermum canum* had the highest germination capacities with a mean of 80.1% and 84.8%, respectively.

DISCUSSION

We provided original data on the germination capacity of 75 species of the Hungarian flora. Compared to the other available germination databases (HUSEED, SID), we used potting soil as a germination substrate, we did not regulate the temperature or dark/light periods, and we sowed seeds without any pre-treatment. Thus, our dataset can give important insights into the germination capacity of plant species under near-natural conditions. This knowledge will support restoration projects in the composition of ideal seed mixtures, containing species that can germinate successfully without additional treatments. Records of the germination capacity of weeds and invasive species can also be informative in nature conservation projects. Our study also highlights that germination capacity can be highly variable between years. This implies that, for successful restoration, the germination capacity of the sown species should be tested in multiple years, and in large-scale projects those species should be prioritized that germinate similarly well every year.

*

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