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Flax weeds in Slovakia: the end of the story?

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Abstract: In Slovakia, seven species of flax specialists has been identified: *Agrostemma linicola*, *Camelina alyssum*, *Cuscuta epilinum*, *Lolium remotum*, *Silene cretica*, *S. linicola*, and *Spergula maxima*. Six of them were reliably documented while occurrence of *S. linicola* is only hypothetical taking into account the occurrence in some surrounding countries in the past. Three taxa had occurred only temporarily and are evaluated as casual neophytes (*Agrostemma linicola*, *Silene cretica*, and *Spergula maxima*). The other three species (*Camelina alyssum*, *Cuscuta epilinum*, *Lolium remotum*) occurred relatively often, especially in areas with large-scale cultivation of flax and well-developed production of linen canvas (Orava region in NW Slovakia and Spiš and Šariš regions in NE Slovakia). They are regarded archaeophytes. While they were relatively common in flax fields in the 19th century, retreating process started after the First World War because flax sown areas decreased by three quarters during the world economic crisis in former Czechoslovakia. In this period, *Cuscuta epilinum* became extinct. The second and crucial phase of vanishing was taking place after WW2. The synergistic effect of several agrotechnical measures caused extinction of two remaining flax-weeds in fifties (*C. alyssum*) and sixties (*L. remotum*). They have belonged to the extinct species of Slovak flora (RE) for more than 60 – 85 years. In addition, with the disappearance of flax weeds, the specific vegetation of the *Lolio remoti-Linion* alliance vanished without a more detailed research. The only possibility to return (at least some) flax-weeds is deliberate sowing in botanical gardens and open-air museums of folk architecture as well as within the framework of increasing the diversity of the agricultural landscape in extensively cultivated fields and bio-belts.

Keywords: central Europe, decline, distribution, flax specialists, flax weeds, rare species.

Introduction

Domestication and cultivation of flax (*Linum usitatissimum* L.) started ca. 9,000 years ago in the Fertile Crescent region although humans used wild flax as a textile 30,000 years ago in Upper Paleolithic times in the Caucasus (Georgia) (Balter 2009; Fu 2011). In Central Europe, Zohary et al. (2012) dated the beginnings of flax cultivation to the middle of the eighth millennium BP.

Flax crops have properties that inhibit the growth of common weeds and allow the development of only a few specialized plant species, so called flax specialist or linicolous weeds (Smejkal 1981; Holzner 1982; Mirek 1997). It is related to the specific requirements of flax for agronomical practices. First, flax needs careful preparation of the soil, then late sowing (mostly around May 15 in Slovakia) and finally the necessary hoeing or weeding. Flax also has specific requirements and biological properties – it is demanding on moisture (over 600 mm of precipitation during the season), germinates at temperatures of 1–2 °C and has a relatively short life cycle lasting 80–110 days (Rothmaler 1946; Špaldon et al. 1982; Černý et al. 2011). Thus, the linicolous weeds used the "window of opportunity": they came to the weed-free fields with imperfectly cleaned flax seed (speirochory).

Flax weeds evolved from their ancestral taxa in direct relation to the cultivation of flax in Europe and Southwest Asia (Hjelmqvist 1950; Smejkal 1981; Kornaś 1988), growth in culture, regular sowing and harvesting dates, methods of seed cleaning and storage selected their populations so that they morphologically and ecologically resemble the cultivated crop. Their common characteristics were a one-year life cycle, height and type of branching similar to the crop, loss of hairs and above all the size, shape and weight of seeds corresponding to flax seeds (Sinskaya & Beztuzheva 1931; Baker 1974; Smejkal 1981; Lososová et al. 2009). For example, Rothmaler (1946) states that in *Lolium* the seed has decreased in size as compared with the seed of the original forms, whereas in *Silene*, *Spergula* and *Camelina* the seed has increased in size, so that in all cases the size of seed will be as near that of flax as possible. Pinke (2005) concludes that flax weeds evolution arose in a relatively short period of time, thousands of years or just centuries. Hjelmqvist (1950) based on morphological differentiation (morphological similarity or difference from flax plants) considered the evolutionary oldest flax weeds *Camelina alyssum*, *Cuscuta epilinum* and *Silene linicola*. On the contrary, *Agrostemma linicola* and *Silene gallica* var. *linophila* were relatively morphologically most different from flax plants and thus the youngest.

The specific group of linicolous weeds has been paid attention in some European countries for a long time (e.g. Rothmaler 1946; Hjelmquist 1950; Kornaś 1961, 1988; Mirek 1976, 1997), but there is no such study in Slovakia except short contribution of Smejkal (1981). The aims of this paper are i) to identify typical flax weeds in Slovak flora, ii) to describe their distribution and iii) to describe reasons of their decline and extinction.

Material and Methods

The study was conducted in the years 2023–2024 by researching data on the distribution of individual species from reliable published sources and own unpublished data. Nomenclature of flowering plants follows Marhold & Hindák (1998). The taxa *Camelina alyssum* and *Spergula maxima* are mentioned in species level because all subspecies of them (*Camelina alyssum* subsp. *alyssum*, *C. alyssum* subsp. *integerrima*, *Spergula maxima* subsp. *maxima*, *S. maxima* subsp. *linicola*) are regarded as flax weeds (Dvořák 1990; Eliáš 2002). Data on the flax crop areas were taken from the work of Binder (1965).

Results of this study are presented in a dot maps. The maps were designed using Corel Draw according to the grid mapping method described by Niklfeld (1971) following rules accepted in the Flóra Slovenska VI/2 (Goliašová et al. 2023). Categories of threat were applied according to the IUCN Red List Criteria (IUCN 2012). Phytogeographical districts published by Futák (1984) are used.

Results and Discussion

Flax specialists and their distribution in Slovakia

In Slovakia, seven species were identified as flax specialists: *Agrostemma linicola*, *Camelina alyssum*, *Cuscuta epilinum*, *Lolium remotum* (syn. *Lolium linicola*, *L. temulentum* subsp. *linicola*, *L. temulentum* subsp. *remotum*), *Silene cretica*, *S. linicola*, and *Spergula maxima* (Tab. 1). Six species have been reliably proven on the territory of Slovakia (Chrtek 1988; Eliáš 2002, 2012; Mereďa et al. 2012; Šípošová 2012; Eliáš & Kšiňan 2024), while the occurrence of *S. linicola* is only hypothetical, it was present in several adjacent countries (Austria, E Poland) in the past (Mereďa et al. l.c.; Schratt-Ehrendorfer et al. 2022). Three species (*Agrostemma linicola*, *Silene cretica*, *Spergula maxima*) were recorded only once or only for a very short period of time; they are considered casual neophytes (Medvecká et al. 2012).

Agrostemma linicola, a species of uncertain origin, is known mainly from Russia, Ukraine and W Asia. Compared to the ancestral *A. githago*, it produced smaller seeds (2.6–3 mm) and has a smooth surface with blunt warts, thus adapting to flax seeds (Hammer et al. 1982). *A. linicola* was found only once (but in large quantities) in a flax field near Čierny Balog village (Central Slovakia, Fig. 1) in 1972. It is possible that the species was introduced there with flax seed imported from the former USSR (Svobodová 1974; Eliáš 2012).

Silene cretica grows in the Mediterranean region from the western part of North Africa and the Iberian Peninsula to W Asia (Turkey, Lebanon, Syria, Palestine), introduced to the Canary Islands (La Gomera) and into North America (Mereďa et al. 2012). The species was temporarily introduced in W Slovakia (Fig. 1) with linseed and was collected in flax fields by J. L. Holuby (1888) near Zemianske Podhradie village (Biele Karpaty Mts, W Slovakia) in 1865 and 1867 and later mentioned by Majerszky (1891) in fields around Borčice village which is not far from locality in the Biele

Tab. 1 Selected characteristics of flax-weeds identified in Slovakia (* occurrence of *Silene linicola* is only hypothetical).

Species	First occurrence data	Last occurrence data	Origin	Status in list of aliens (Medvecká et al. 2012)	References
Agrostemma linicola	1972	1972	Uncertain (E Europe, W Asia)	neophyte	Eliáš 2012
Camelina alyssum	1873	1952	Europe, Asia Minor, W Siberia, Transbaikalia	archaeophyte	Eliáš 2002
Cuscuta epilinum	1806	1939	most of Europe, N Asia	archaeophyte	Chrtek 1988
Lolium remotum	1830	1962	Uncertain (Europe to Central Asia, N. Africa)	archaeophyte	Eliáš & Kšiňan 2024
Silene cretica	1865	1891	N Africa, Europe, W Asia	neophyte	Mereďa et al. 2012
Silene linicola*	?	?	S, W and Central Europe	not evaluated	Mereďa et al. 2012
Spergula maxima	1909	1909	Central and E Europe, W Asia	neophyte	Šípošová 2012

Karpaty Mts. No other data are known, however, it is likely that *S. cretica* occurred sporadically and temporarily also in other areas of Slovakia in the past (Mereďa et al. l. c.).

Nominate subspecies *maxima* of a Eurasian species *Spergula maxima* was found only once at fields near the Košice town (E Slovakia, Fig. 1) in 1909 (Šípošová 2012). Because both subspecies (subsp. *maxima* and subsp. *linicola*) are characteristic as weeds of flax fields (Dvořák 1990; Kaplan et al. 2020), we included it in the survey. L. Thaisz, the head of the Košice branch of Institute for Seed Control in Budapest (Mikoláš 1991), collected *S. maxima* in his herbarium. The Institute dealt, among other things, on seed growing, seed quality testing and seed falsification preventing, so *S. maxima* could have reached the site as an admixture of tested seeds from the southern parts of the Austro-Hungarian Empire.

The remaining three species can be considered typical flax weeds in Slovakia, they are regarded archaeophytes in the flora; it is assumed that they appeared before the 15th century (Medvecká et al. 2012). *Camelina alyssum* is an antropophyte species occurred in Europe and Southwest Asia; it was introduced in the Eastern Africa and South America (Smejkal 1971; Mirek 1981; Eliáš 2002; Dorofeyev 2019). Distribution range of *Cuscuta epilinum* included almost all of Europe and further east through Russia to the Ob River; rare occurrences were in Asia Minor, in the east Mediterranean, in the Caucasus, in Iran and Afghanistan (Chrtek 2000). Distribution range of *Lolium remotum* is unclear due anthropophytic spreading within times, Nikitin (1983) regarded it as mostly European, Conert (1996) and Terrel (2007) as Eurasian and North African species, others mentioned it native in Asia from northern Pakistan to Western Himalaya (POWO 2024). In Slovakia, all above three species were relatively common in flax fields. Their occurrence was mainly concentrated in areas with suitable conditions for the flax cultivation and the linen cloth production

– namely, the regions in the north-western and north-eastern of Slovakia – Orava, Spiš, Šariš and Pieniny (Fig. 2 – 4). The centre of linen production from the Middle Ages to 20th century was Spiš region (NE Slovakia), followed by Orava (NW Slovakia) and Šariš as well as Pieniny regions (NE Slovakia) (Štefánik & Lukačka 2010; Beňušová & Kulášová 2018; Špiesz 2021). However, there is lack of data from Orava region in Slovakia (*Camelina alyssum* and *Cuscuta epilinum* are reported from 1 locality, *Lolium remotum* was found at 2 localities), although there is enough data from the adjacent territory of Poland (Zając & Zając 2001). Eliáš & Kšiňan (2024) explained due to the absence of botanical research of (flax) fields in the area. On the contrary, quite a lot of data are from the Biele Karpaty Mts area, where linen was not the main source of livelihood. However, J. L. Holuby, one of the most important Slovak botanists of the 19th century, worked here (Vozárová 2010a). J. L. Holuby intensively researched the flora of this area, e.g. he collected *L. remotum* here in 1865, 1870, 1882, 1895, 1897 and 1914 (Eliáš & Kšiňan 2024). Similarly, we have relatively well documented distribution of flax weeds on the Spiš region because A. Hazslinsky, S. Dietz as well as V. Greschik worked here from the middle of the 19th century to the first half of the 20th century (Koudela 2010; Chromý & Vozárová 2010; Vozárová 2010b). In connection with the evaluation of the incidence of flax weeds in Slovakia we can therefore draw two conclusions from the above: i) the amount of data is strongly dependent on the intensity of botanical research in the given region and ii) the linicolous weeds occurrence was probably much more common in this period.

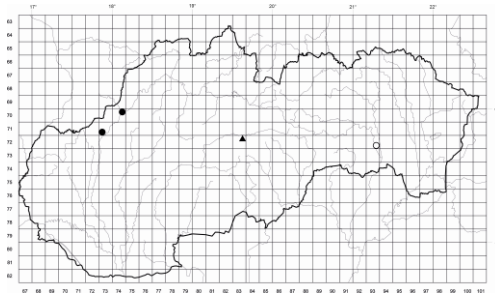

Fig. 1 Past distribution of *Agrostemma linicola* (triangle), *Silene cretica* (black circles) and *Spergula maxima* (empty circle) in Slovakia.

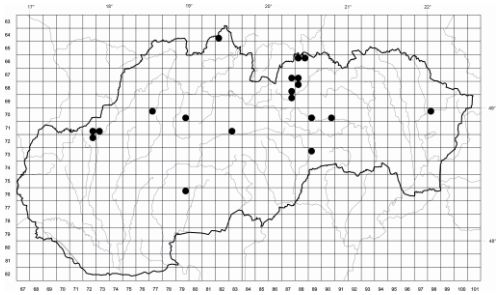

Fig. 3 Past distribution of *Cuscuta epilinum* in Slovakia.

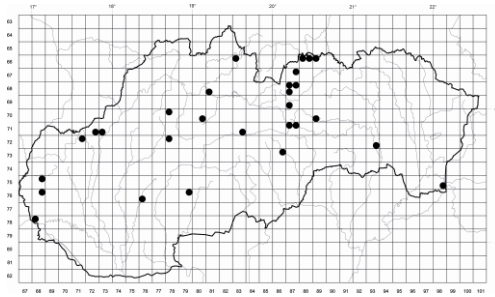

Fig. 2 Past distribution of *Camelina alyssum* in Slovakia.

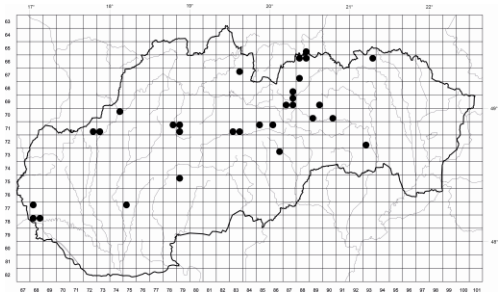

Fig. 4 Past distribution of *Lolium remotum* in Slovakia.

In the later period, the intensity of botanical research increased (Smejkal 1981; Hendrych 1996), but specialized linicolous species were already on the decline.

Decline and extinction of linicolous species

The spread of flax specialists has always been associated with flax cultures, while their specialization was evolutionarily reflected in the plant habitus as well as weight and seed morphology very similar to flax stems and flax seeds (Kudryavtsev et al. 2021). This speirochoric seed dispersal has been a very successful strategy for many centuries that man has not been able to eliminate. Simple methods of mechanical seed cleaning even contributed to the mass spread of flax weeds in the first quarter of the 20th century in Northern and Eastern Europe. The profitability of flax cultivation decreased despite continuous seed cleaning, speirochoric species accounted for 35 – 99% of linseed contamination (Pinke & Pál 1995). The survival of flax weeds was also supported by the mass cultivation of their host crop. At the end of the 19th century, the flax cultivation areas on the territory of the former Czechoslovakia (northern part of the Austro-Hungarian Empire at this time) were at the level of around 30 – 45 thousand hectares. A more pronounced decrease in cultivated areas occurred during the WW1, but above all during the global economic crisis (1929 – 1933). A more significant increase in flax cultivation areas is documented only after the WW2 (Binder 1965, Fig. 5). If we compare these data with the occurrence of flax-weeds, in the case of *Cuscuta epilinum* and *Lolium remotum*, there is a clear trend of a significant decrease in locations in the period before WW2 (Fig. 6). *Cuscuta epilinum* probably became even completely extinct during this period in Slovakia, it was last recorded in 1939 (Chrtek 1988). This trend was also confirmed in the Czech Republic, *Cuscuta epilinum* was a rare species in the period 1930 – 1939, only 8 locations were documented in the period between 1940 – 1945, and it completely disappeared in the fifties (Chrtek 2000; Drlík et al. 2005).

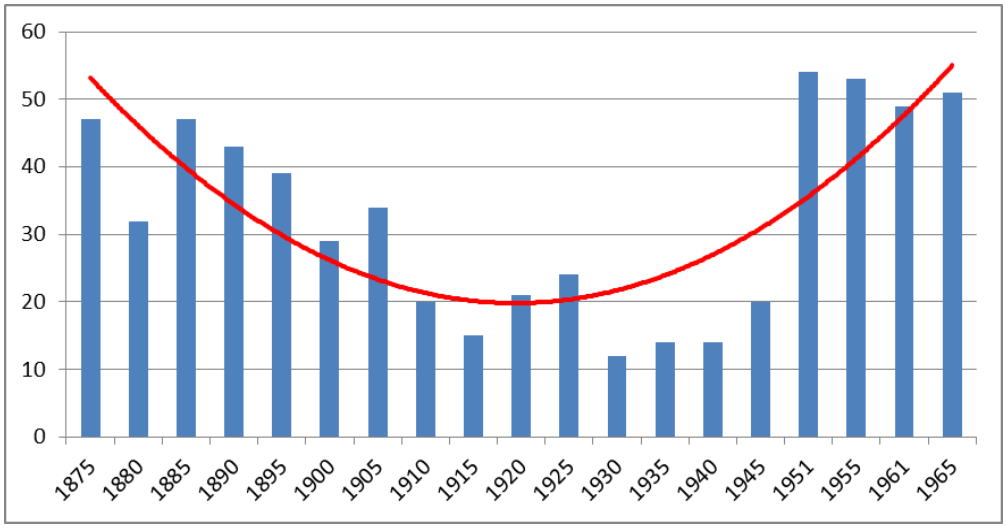

Fig. 5 Cultivated areas of flax (*Linum usitatissimum*) in thousands of ha in former Czechoslovakia (Binder 1965).

A parasitic way of feeding may also have contributed to its rapid decline, although it can survive for a short time on other hosts (e.g. on *Impatiens* species) besides flax (Costea & Tardif 2006). Occurrence of annual grass *Lolium remotum* decreased also rapidly, however, it survived of all those three linicolous weeds the longest in the Slovak flora, the last data is from 1962 (Eliáš & Kšiňan 2024). It is interesting that *L. remotum* also survived the longest of all flax weeds in the Czech Republic – the last herbarium voucher is from 1961 and the last published data from 1974 (Špryňar 2024). It is quite likely that this may be related to the method of linseed cleaning in the former Czechoslovakia. While *Cuscuta epilinum* and *Camelina alyssum* seeds were successfully eliminated, at least some *L. remotum* grains could remain among the *Linum usitatissimum* seeds. It is also significant that *L. remotum* grains were the most similar in shape and size to flax seeds (Boros 1950). The extinction process of *Camelina alyssum* has a different trend, as already found by Smejkal (1981). In the period after WW1 and at the time of the world economic crisis, there was a reduction in occurrence, but then the number of localities temporarily increased, only to be followed by a sharp fall and extinction in the 1950s (Fig. 6) because last locality was recorded in 1952 (Eliáš 2002). The reasons are not clear, the reduction in flaxseed cleaning during World War 2 did not cause this, because then the number of locations of other flax weeds would also have increased. A certain reason could be the attractiveness of *C. alyssum* plants to botanists during flowering (yellow flowers) and after fruit formation (relatively large pyriform fruits) and the same plant height

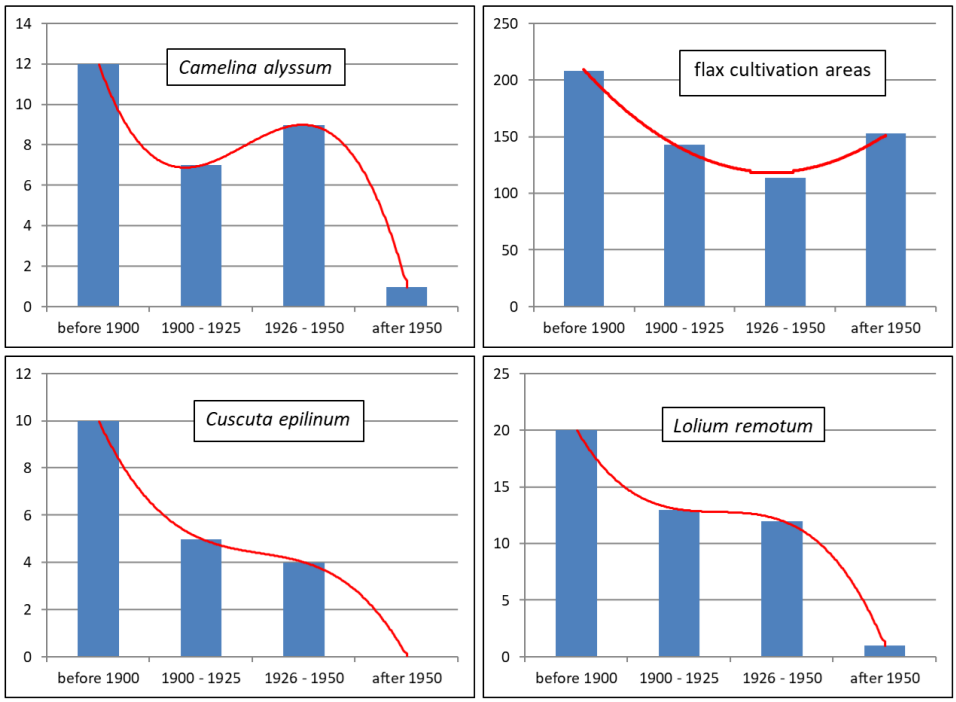

Fig. 6 The process of disappearing of *Camelina alyssum*, *Cuscuta epilinum* and *Lolium remotum* compared to flax cultivation areas in former Czechoslovakia (in thousands of ha).

as flax. Botanists could thus see *C. alyssum* plants earlier than other weeds – *Cuscuta epilinum* was very rare or extinct during this period, it parasitized mainly in the lower parts of the flax stem, and *Lolium remotum* does not have distinctive flowers, it has a subtle body structure. Thus, both last mentioned species could be easily overlooked. The second reason could be that *C. alyssum* was able to survive for a short time in other field crops (cereals) and in ruderal habitats as was reported from the British Isles (Clapham et. al. 1987). The last data from Slovakia is also from such type of habitat (quarry). However, even the ability to survive in several types of habitats did not prevent its extinction.

So, we believe that the process of disappearance and extinction of specialized flax-weeds had two phases in (Czecho)Slovakia. The first phase is related to the reduction of flax cultivation during WW1 and the world economic crisis. The distribution area became fragmented and gene flow within local populations was severely restricted, the level of flax seed cleaning also advanced. The second, decisive phase began after the WW2, while the synergistic effect of several agrotechnical measures (precise cleaning of the seed, simplification of crop rotation, deep autumn plowing, and application of herbicides) manifested (Eliáš & Kšiňan 2024). For example, magnetic powder was applied to clean flax seeds because it coated coarsely pitted rough surface of *Cuscuta epilinum* seeds which were easily eliminated in electromagnetic machines. In addition, the effectiveness of herbicides increased and reduced the presence of weed species from 40 – 50% (MCPA) to 90% (modern sulfonylureas) (Kudryavtsev & Zaitseva 2018; Kudryavtsev et al. 2021). Intensification of agriculture caused the homogenization of the weedy species composition of field crops and until then common weeds as *Agrostemma githago*, *Bromus secalinus*, *Cyanus segetum*, *Scandix pectin-veneris*, *Silene gallica* etc. became rare or extinct (Ripka & Mereďa 1999; Devánová et al. 2006; Eliáš et al. 2007; 2010; Meyer at al. 2013; Pinke 2020; Kolářová et al. 2023). In the case of flax fields, there is an obvious global trend of replacing specialized flax weeds with "cosmopolitan" weeds associated with root crops and cereals (Heller 2010; Bilalis et al. 2012; Kudryavtsev et al. 2021).

In addition, specific flax field vegetation also vanished due to the retreat and extinction of linicolous weeds (Mucina et al. 2016). A separate alliance *Lolio remoti-Linion* of flax-field weed vegetation was distinguished in Germany, Hungary and Poland (Rennwald 2000; Borhidi et al. 2012; Matuszkiewicz 2024). This vegetation type was apparently present in the Czech Republic and Slovakia in the past, but relevant phytosociological relevés are missing (Lososová et al. 2006; Eliáš sen. 2007; Jarolímek et al. 2008).

The end of the story

Disappearance of linicolous weeds after WW2 (especially in 1950s and 1960s) was observed in a number of European countries (Eliáš 1987, 2007; Mirek 1997; Zając et al. 2009; Pinke et al. 2011; Storkey et al. 2012; Meyer at al. 2013; Fanfarillo et al. 2020; Fried 2020; Hyvönen et al. 2020 etc.). The extinction of this group of highly specialized species not only impoverished the diversity of agrocenoses (Pinke & Pál

Tab. 2 Red List status of flax weeds in Central and East Europe (Király 2007; Eliáš et al. 2015; Kaźmierczakowa et al. 2016; Grulich & Chobot 2017; Onyshchenko et al. 2022; Schratt-Ehrendorfer et al. 2022). Explanations of IUCN categories (IUCN 2012): CR – critically endangered, DD – data deficient, EW – extinct in wild, EX – extinct, NA – not applicable, RE – regionally extinct.

Species	Austria	Czech Republic	Hungary	Poland	Slovakia	Ukraine
Agrostemma linicola	Not present in flora	Not present in flora	Not present in flora	Not present in flora	Not included in RL	Not included in RL
Camelina alyssum	RE	RE	EW	EX	RE	NA
Cuscuta epilinum	RE 1954	RE	EW	RE	RE	DD
Lolium remotum	RE 1950	RE	EX	CR	RE	NA
Silene cretica	Not included in RL	Not included in RL	Not included in RL	Not present in flora	Not included in RL	Not present in flora
Silene linicola	RE	Not present in flora	Not present in flora	Not included in RL	Not included in RL	Not present in flora
Spergula maxima	RE	RE	Not included in RL	RE	Not included in RL	NA / DD

2005; Meyer et al. 2013), but also eliminated a group of species suitable as objects for the study of microevolution and anthropogenically conditioned evolutionary selection (Smejkal 1981). Currently, they are extremely rare or extinct in Central and Eastern Europe (Tab. 2). In Slovakia, we can conclude that the story of flax weeds is finished; all taxa are extinct in the flora more than 60 – 85 years (Eliáš et al. 2015). Cultivation of fiber flax was practically stopped at the beginning of the new millennium, and oil flax is grown only to a limited extent on an area of less than 1500 – 2000 ha in last ten years (Izakovičová 2023). The flax seed is cleaned to a high standard and effective herbicides are applied during cultivation, ecological niche was occupied by common weeds of root crops and cereals. Introduction of flax specialists via poorly cleaned flax seed from Asia or Africa is potentially possible but unlikely. Apparently, the only possibility to return (at least some) flax-weeds is deliberate sowing. This could be practiced within botanical gardens and open-air museums of folk architecture (Pinke & Pál 2005; Eliáš sen. 2007) or within the framework of increasing the diversity of the agricultural landscape in extensively cultivated fields as well as bio-belts (Pinke et al. 2008; Pywell et al. 2010; Albrecht et al. 2016; Šálek et al. 2018; Hanusová et al. 2022; Rischen et al. 2022). The recent findings of the critically endangered species *Agrostemma githago* and especially the regionally extinct taxon *Camelina sativa* subsp. *zingerii* can serve as a good example; they were probably deliberately sown on a private field and in bio-belt, respectively (Dudáš et al. 2024).

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