Genet Resour Crop Evol (2021) 68:3039–3053
https://doi.org/10.1007/s10722-021-01219-z

NOTES ON NEGLECTED AND UNDERUTILIZED CROPS

Rise and fall of *Stachys annua* (L.) L. in the Carpathian Basin: a historical review and prospects for its revival

Gyula Pinke · Éva Dunai · Bálint Czúcz

Received: 14 February 2021 / Accepted: 21 May 2021 / Published online: 30 May 2021

Abstract *Stachys annua* (L.) L., a melliferous archaeophyte plant became a dominant weed of the cereal stubbles of the Carpathian Basin in the medieval three-field system. By the middle of the nineteenth century, this plant provided more than two-thirds of the Hungarian honey production, and its high quality monofloral honey turned into a characteristic brand of the Hungarian apiculture. Recognizing its importance, *S. annua* also briefly became a minor crop cultivated in "bee gardens" and arable fields in the late nineteenth century, possibly also in response to the first signs of its upcoming decline. Starting with the advent of the steam plough, the twentieth century has brought a drastic decline for *S. annua* due to a combination of deeper and earlier tillage operations, agrochemicals, and new competing weed species (in particular the common ragweed, *Ambrosia artemisiifolia*). The last remnant stands of this previously dominant weed species are of considerable ecological and historical value as farmland biodiversity hotspots. These sites are important refuge for rare weeds, wild pollinators (including bumblebees), and declining farmland birds, which could be targeted by eco-schemes under the European Union's (EU's) greening Common Agricultural Policy. The rediscovery of the cropping potential of *S. annua* and the development of an appropriate technology would also allow its cultivation as a valuable bee forage, catch crop, green cover, or oilseed plant in the future.

Keywords Apiculture · Beekeeping · Ethnobotany · Honeybee · Nectar · Neglected and underutilized crops · Stubble · Transhumance · Weeds

G. Pinke (✉) · É. Dunai
Faculty of Agricultural and Food Sciences, Széchenyi István University, Vár 2, 9200 Mosonmagyaróvár, Hungary
e-mail: pinke.gyula@sze.hu

B. Czúcz
European Commission, Joint Research Centre, Via Fermi, 2749, 21027 Ispra, Italy

Introduction

Stachys annua L. (annual yellow-woundwort or annual hedgenettle) is one of the members of the *Stachys* genus from the *Lamiaceae* family. The plant is distributed in large parts of Europe (Tutin et al. 1990). For instance, it is abundant in south-western Russia (Sokolova et al. 2004) as well as in southern Italy (Perrino and Calabrese 2018), sporadic in Albania (Barina et al. 2017), but mostly very rare and endangered in the more northern and western European locations (Kästner et al. 2001; Skrajna et al. 2018; Kaplan et al. 2019). It is widely distributed in Turkey (Akcicek 2020), frequent in northern and eastern Iraq, Georgia and Iran (Salmaki et al. 2012).

In the Carpathian Basin, there are 17 *Stachys* species that can occur in the wild (Jávorka and Csapody 1991). Among these there are two species, *S. palustris* L. and *S. annua*, which can be regarded as arable weeds (Király 2009). Both of these species are also of a great ethnobotanical importance: *S. palustris* is known for its edible tubers (Łuczaj et al. 2011; Darbyshire et al. 2014), while *S. annua* can produce abundant quantities of high quality honey. Nevertheless, while the beekeepers of the Carpathian Basin are still broadly aware of the cultural importance of this once abundant plant species, the potentials and the related rich history of *S. annua* is fairly unrecognized for an international readership. According to the extensive European survey of Persano Oddo et al. (2004), monofloral honeys from *S. annua* are known only from Italy and Spain, suggesting that this honey plant was either not utilized or forgotten in the rest of Europe.

As Hammer et al. (2001) highlighted, many underutilized and neglected species are adapted to various marginal growing conditions, which is particularly true for *S. annua*, not only in abiotic but also in a phenological aspects. The plant, which thrives on mountainous slopes in Asia in its centre of distribution (Salmaki et al. 2012), found a very special phenological niche towards the edge of its range in the Carpathian Basin, where it became a major weed of arable stubbles. Its development usually starts in May (Fig. 1a), under the shelter of the cereal stands but it flowers only after harvest, in response to the favourable light conditions created by the removal of the dense crops (Pinke and Pál 2009) (Fig. 1b). One of its common Hungarian names, 'tarlóvirág' also refers to its main blooming habitat, as it literally means 'stubble-flower'. Its mass-blossom can be very spectacular (Fig. 1c), as from certain perspectives, its dominant stands are reminiscent of a snow-covered landscape due to its thousands of white-yellowish corollas (Fig. 1d). It grows in many kinds of base-rich soils, but it is able to create lush vegetation and produce high amount of nectar only in heavier substrates if the summer is warm and rainy together with dewy nights (Papszt 1933).

The aim of this review article is to raise attention to this underutilized honey plant and describe its unique history and biodiversity. This was done in the hope that the plant can still have a bright future in Europe as a cultivated bee pasture plant.

Historical relevance and uses

From its native Anatolian-Armenian region, *S. annua* was introduced to Europe as an archaeophyte (Kästner et al. 2001). Its archaeobotanical remains in the Carpathian Basin have been detected already from the late Neolithic times (Gyulai 2010). The plant has probably become a dominant arable weed in the medieval three-field rotation systems, where it found favourable ecological conditions in the relatively undisturbed cereal stubbles. At that time stubbles were not ploughed right after harvest, but the sprouting weeds were grazed by livestock (Wellmann 1967). *S. annua* was a good forage for sheep (Kovács 1991), but due to its pungent taste livestock preferred to avoid it as long as other weeds were also available (Mrena 1937). Although, the melliferous quality of the bee pasture in the stubble was strongly influenced by the intensity of grazing (Sötér 1908), a moderate grazing could still create favourable conditions for *S. annua* and its apicultural use (Balassi 2001). Reportedly, in the last decades of the nineteenth century, this plant was still so abundant that besides grazing, it was also mown for winter bedding in animal stalls (Ignácz 1929).

Even though the history of apiculture in the Carpathian Basin during the last millennium has been most explicitly reviewed by Sötér (1908) and Szabadfalvi (1992), the oldest documents lack an accurate specification of the floral resources used. Therefore, whereas we know that forest beekeeping flourished during the Middle Ages in Eastern Europe's woodlands (Kritsky 2017), the exact date when the manufacturing of 'stubble honey' started in the Carpathian Basin is not known. Káldy-Nagy (1970) pointed out that in the sixteenth century, the Turkish occupants ordered the beekeepers that their beehive tax had to be shared between the lord of the residency and the lord of the land where beehives were placed at the time of blossom. This suggests the presence of mass-flowering melliferous plants on cultivated land as well as a migratory beekeeping practice. Perhaps already in those days, beehives were displaced from floodplain forests and fruit wooded vineyards into the stubbles after harvest. The first direct evidence for regular transhumance of this kind comes from Southern Hungary in the eighteenth-century: "*Honey gathered from arable land is better and more than any others (…) it was as if there had been white sheet on the fields*

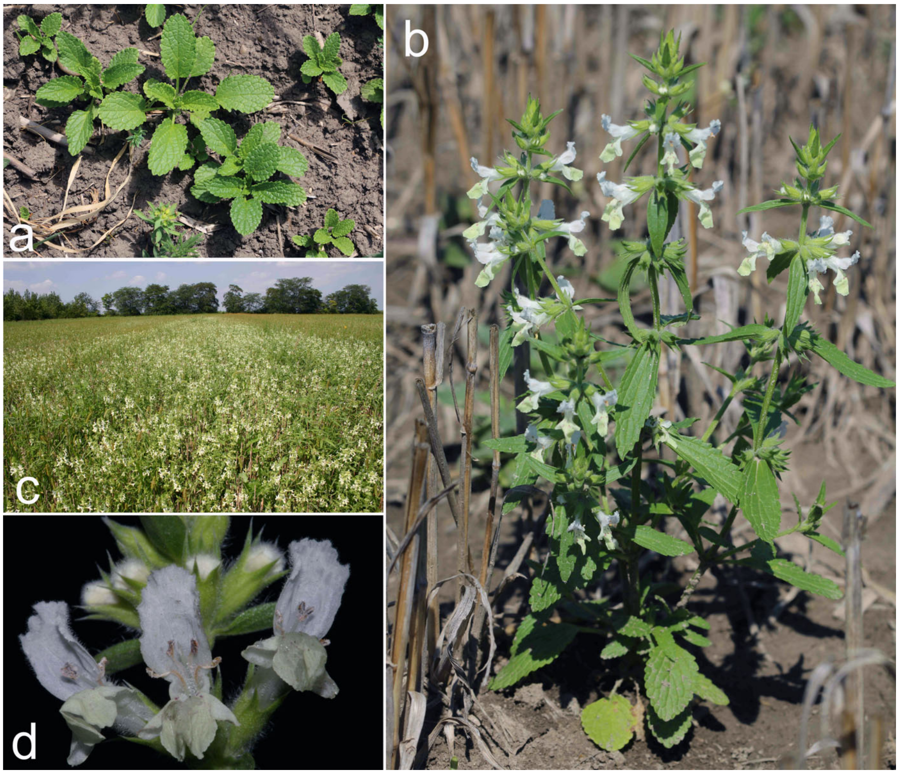

Fig. 1 *Stachys annua*. **a** Young plants in May. **b** A flowering plant in August. **c** Mass blossom in a cereal stubble (Kálóz, central Hungary, 2005). **c** Inflorescence with the white-yellowish corollas. (photo: Pinke G)

from the stubble-flower (…), the beehives were placed simply on the ground in the fields" (Andrásfalvy 1975, p 426). Kalo (1816) mentioned in one of the earliest printed Hungarian beekeeper books that *S. annua* "*is thriving abundantly, particularly during humid hot spells, in wheat and barley stubbles without cattle grazing, and bees can gather very much fragrant honey*" (Kalo 1816, p 260). This suggests that certain stubbles were designated for apiarian purposes by excluding grazing livestock. The considerable prosperity of Hungarian beekeeping in the seventeenth to eighteenth century can probably also be attributed to the large bee pastures offered by the stubbles dominated by *S. annua* (Benkő 2019).

Previously, *S. annua* was referred to as the "*king of the melliferous plants*" in Western Hungary (Pataki 1910). Nevertheless, in the second half of the nineteenth century East Hungary has gained also a good reputation as the "*homeland of snow-white stubbles*" (Szabó 1979), the "*El Dorado*" of stubble-flowers (Kurpé 1928), the "*goldmine of lowland beekeepers*" (Marossi 1920), or even as the "*land of the covenant*" (Puskás 1941). In this part of the country, where the three-field system has persisted for the longest time and was still dominant at the turn of the twentieth century (Frisnyák 1990), in certain years the arable lands covered by stubble-flower were so white, "*as if snow had fallen*" (Binder 1898), or "*as if they had been fascinating crop fields*" (Hazslinszky 1955). This vegetation sometimes produced so much honey "*that beekeepers were not able to get enough pots for it*" (Némethy 1929). In these summers, beekeepers congregated for the stubble blooming, lining up with thousands of beehives around the most valuable places (Némethy 1929). The grateful appreciation of the beekeepers for this plant was perhaps most eloquently summarized by Koppány (1930 p 305): "*Stubble-flower, our most excellent late summer melliferous plant, is a true blessing of providence, and its pure goodwill for apiculture*".

In the middle of the nineteenth century, *S. annua* provided more than two-thirds of the Hungarian honey production (Szilassy 1911). From dense *S. annua* stands at the peak of flowering a bee colony could gather as much as 8 kg of honey in a day under favourable circumstances (Berkó and Kardos 1937), nevertheless this amount was normally between 2–3 kg/day (Juhász 1983) (Fig. 2a). Thus, the daily nectar production of *S. annua* was not as high as that of false acacia (*Robinia pseudoacacia* L.), but its honey-producing period lasted much longer, usually more than 6–8 weeks and during this period a bee family could gather 50–100 kg of honey (Nyárády 1958). However, its nectar production was highly dependent on weather conditions with a variable floral nectar content (0.19–1.05 mg/flower/day) and sugar concentration (17.88–47.12%, Péter 1973). Accordingly, in every ten years, three were excellent, four were moderate and three were bad in terms of its honey yield (Horváth 1924). Crane and Walker (1985) reported measurement results about the plant from Italy and Romania, with 12 mg/flower/day nectar sugar flow and a honey potential of 88–550 kg/ha. Along with nectar the white pollen of *S. annua* was also collected by honeybees. Due to the characteristic geometry of *S. annua* flowers, a peculiar star-shaped white mark was left on the forehead of the foraging bees (called by beekeepers as 'hóka', an old Hungarian word only used for a similar white star mark on horse foreheads; Koppány 1930). The appearance of these

Fig. 2 **a** A honeybee visits *S. annua*. **b** A farmer disc harrows the stubble covered by *S. annua* instead of utilizing its apicultural potential (Jánossomorja, north-west Hungary, 2020). (photo: Pinke G) **c** Honey of *S. annua* from Mali Iđoš, northern Serbia (source: Hét Nap Online)

marks signalized the beginning of the nectar collection from stubbles for the beekeepers in older times (Koppány 1930).

There were several factors that contributed to the outstanding apicultural significance of *S. annua.* The 'stubble-flowers' were a major floral resource in an otherwise nectar-scarce period of the year, which as the beekeepers of the period emphasized, used to guarantee the strengthening and safe overwintering of bee colonies (Farkas and Zajácz 2007). Nevertheless, the main value of this species was its monofloral honey, which was regarded as one of the most delicious honeys for human consumption (Ambrózy 1896). As a good quality product specific to the Carpathian Basin, this honey was proposed as a potential "world brand" of Hungarian agriculture (Radnóti 1937). Pure honey derived from *S. annua* was described as a bright, water-clean honey with an intensive pleasant scent and aroma. Depending on the presence of nectar from other plant species, the original colour of the honey could also be yellowish or even brown. Nevertheless, due to its high dextrose content, monofloral *S. annua* honey would crystallize very quickly (within 1–2 months) into a typically white, sometimes yellowish creamy state, and most consumers would know (and appreciate) it in this state (Weiser 1919; Stitz 1928; Hazslinszky 1952).

This creamy honey with its strong and characteristic scent used to be considered as a true medical honey (Anonymous 1930). The medicinal uses attributed to the honey may be related to the medicinal uses of the plant itself, which were for treating colds, spasms, epilepsy and urinary infections (Anonymous 1981). One of its traditional Hungarian names, 'tisztesfű' also refers to its medicinal (cleansing) properties ('tiszta', Rácz 2010). However, the most ancient use of this species is probably the treatment of an 'evil eye' in superstitious healing procedures based on the fumes of the plants or a bath prepared from it (Temesváry 1899; Vargyas 1945; Kóczián 2014). In a case documented in 1931, a gipsy herb woman placed a dog skull into a tub, poured potion of *S. annua* on it, and after the water got cold she bathed an ill child in it (Kászonyi 1931). It should be noted that *S. annua* and *S. recta* L. (perennial yellow-woundwort, a plant thriving in non-arable habitats) might be mistakenly regarded as the same species by folk medicine, which had also happened in some old apicultural sources (Lengyel 1921). In fact, originally *S. recta* could be believed to possess such remedial power which was supposedly attached also to *S. annua* in the course of time (Wagner 1902). Interestingly, *S. annua* (together with other *Stachys* species) was also used for treating evil eye in Italy (Lucchetti et al. 2019; Tomou et al. 2020). In Italian folk medicine, the aerial parts of *S. annua* were used as anti-catarrhal, febrifuge, tonic, and vulnerary as well (Venditti et al. 2015). *Stachys* species were used also in Turkey for the treatment of cold, stomach ailments, fever and cough in the form of herbal infusions and decoctions (Gören 2014). Moreover, antimicrobial, antioxidant and cytotoxic activities of *S. annua* were also documented, induced by its secondary metabolites (such as diterpenoids, flavonoids and phenolic acids) (Tundis et al. 2014; Kocak et al. 2017; Movsumov et al. 2018; Bursal et al. 2020).

It should be pointed out that monofloral *S. annua* honey might have been known and produced in other parts of Eastern Europe, beyond the Carpathian Basin. An eminent Hungarian beekeeper, who was enrolled as a reserved officer during the Second World War (WW2), reported about incredibly vast fields of *S. annua* in Russia (Szabó 1942). Interviewing local beekeepers, Szabó (1943a) also recorded stories of a special Caucasian bee race with a longer tongue that was introduced in the kolkhoz system to make nectar collection from this flower more efficient. These records suggest that similar to the Carpathian basin, *S. annua* could have been a significant melliferous resource in several countries of Eastern Europe, and the Russian scientific literature could still hide several studies exploring the potential of this plant.

Cultivation experiments

Due to its high apicultural importance, *S. annua* also became a sporadically cultivated species in Hungary at the end of the nineteenth century. This was first documented by Göndöcs (1886) and Ludvig (1887) as a practice intended to enhance the reliability of bee pastures: "*The year before* (which was highly unfavourable year for apiculture)*, there were no fruit tree flowers, rapeseed and acacia froze, stubble-flower in the fields died out due to the summer drought. Bees were dying everywhere, except for mine, because I sowed stubble-flower seeds in my garden multiple times, from which there was a continuous supply of flowers from June to October. Next year I will sow* *even more*" (Ludvig 1887, p 68). Göndöcs (1886) also described his technology, including how he gained seeds from spontaneous stands in wheat stubbles. According to his experience, spring sowing worked better than autumn sowing. On the contrary, Krenn (1886) who grew *S. annua* on behalf of the Ministry of Agriculture in a state estate, found spring sowing less appropriate because of dry soil conditions. The editor of the Apicultural Bulletin of the Transylvanian Beekeeper Society noted that the plant was already propagated by many beekeepers at that time, but usually with little success due to the bad quality of seeds (Turcsányi 1891). He encouraged the readers to buy certificated seeds from a particular producer. Afterwards, Fényes (1915) recommended that this plant should be grown at least in two stripes in every village garden, for which, as he said, the seeds were easily available at the beekeeper shops of the period. Nevertheless, Uhlárik (1917), who also retailed the seeds of *S. annua*, emphasised that small-scale cultivation (in garden beds) could not improve bee pastures on a country-wide scale, for this purpose a deliberate cultivation in arable fields would be necessary. He also envisioned a farmers' movement, where seeds would be sown in rye and wheat fields every autumn during 4–5 consecutive years (a crop rotation cycle), so that they could be dispersed in every parcel of the participants, even if they were sown sparsely by hand (Uhlárik 1917). By any means, efforts for its naturalization in regions with unfavourable soil and weather conditions, definitely resulted in little success (Nagy 1918). These records suggest an active community engaged in the cultivation, promotion and seed trade throughout the Carpathian Basin.

There are many documents in the literature that several farms, agricultural schools, and state institutions made cropping experiments with *S. annua* (Mrena 1937), and the emerging new honey crop also attracted international seed requests from the National Seed Testing Institute in Budapest (Lengyel 1943). Fucsek (1901) and Mrena (1937) published detailed practical guides to the cultivation and seed saving of *S. annua*, from which a brief synthesis is described henceforward. First, mature plants in the fields were collected, dried, and threshed by hand or with a lucerne threshing machine. Seeds were stored in a dry and airy place and sown in next February or March to a depth of 1–2 cm in a well-elaborated seedbed. Except for a possible hoeing or hand weeding right after the emergence, no management activities were needed. Plots sown with *S. annua* could provide a good bee pasture from May to the first autumn frosts. Cultivated *S. annua* plants grew larger and more luxuriant than spontaneous individuals in the arable stubbles. Once the plant is established in a garden it could sow itself, only the soil had to be tilled in every spring (Fucsek 1901). However, the laborious steps of seed saving were reported to make the cultivation difficult (Uhlárik 1916).

While Lengyel (1943) still recommended a targeted program for the cultivation and breeding of *S. annua* (also suggesting its potential use as an oilseed plant), all experiments were stopped again by the new war. Nyárády (1958) suggested the selection of cultivars with seeds that will not shatter, and a shorter corolla tube. This latter trait seemed to be important to increase the yield of nectar available for honeybees in unfavourable conditions (e.g. dry weather or light soils), when nectar levels tend to drop too low for honeybees to reach. According to Ujvárosi (1973), the arable cultivation of *S. annua* was also greatly hindered by its unevenly germinating seeds; the emergence is partial, and the dormant seeds appear as weeds in the subsequent crops of the rotation. This is not surprising, given that the centuries of three-field system were selecting for a weed population that could wait 2–3 years in the seed bank for the ideal conditions to reappear. Nevertheless, this tendency for dormancy needs to be removed so that *S. annua* could be developed into a versatile crop.

The three phases of decline

Since the middle of the nineteenth century *S. annua* populations are in a steady decline, which has turned the former king of arable stubbles into a botanical curiosity in many regions today. This process can be split into three main phases according to the dominant factors behind the recession.

Worrying trends in *S. annua* populations have been reported from the beginning of the twentieth century, which were attributed primarily to the spread of steam plough. This new equipment allowed the tillage of large areas within a short time, and not least, the deep plough of heavy soils (Estók et al. 2003). Consequently, the surface of stubbles and fallow lands in the main distribution range of *S. annua* decreased significantly during this period (Pataki 1910; Szilassy 1911). Furthermore, steam tillage buried weed seeds much deeper, from where *S. annua* was not able to emerge (Péter 1973). This tendency in relation with the changing tillage and cultivation patterns, however, was mostly restricted to the market-oriented large estates, while *S. annua* and the associated apiculture could still thrive in the smaller farmyards sometimes still managed in a field system (Héjjas 1934). In parallel, after the demise of the Austrian-Hungarian monarchy, Hungary has lost most of its historical forests, and false acacia (*R. pseudoacacia*) was widely planted in afforestation campaigns in the lowlands (Bartha et al. 2008). Therefore, *S. annua* lost its status of being the most important Hungarian honey plant and was relegated to second place along this ranking behind false acacia (Széll 1931). The different soil-preferences of these two species generated new patterns in transhumance; beekeepers also started to migrate between the sandy regions prevailed by *R. pseudoacacia* and the clayey-loamy provinces of *S. annua* (Szám 1937), making use of the gradually improving transport infrastructure of the country.

The end of WW2 might have been a turning point in the history of the plant, introducing a second phase of steep decline. Szabó (1943b) already sounded an alarm in 1943 prophesying that the upcoming "new agriculture" could lead to a "*silent demise*" and an "*almost complete elimination*" of *S. annua*. He also suggested that cooperation between beekeepers, farmers and scientists would be necessary to prove the diverse benefits of this plant (including novel considerations, like its positive impacts on soil humus supply, Szabó 1944). Nevertheless, most of the leading agronomists of the era committed to industrialised agriculture optimized for the sole criterion of maximal crop production in almost all countries of the Carpathian Basin (Pinke 2020a). Following the new protocols, stubbles had to be ploughed up or harrowed immediately after harvest, causing the species to fail to set flower and seeds. This new practice of stubble ploughing has been sharply criticized by beekeepers and shepherds in public Hungarian newspapers (Pinke 2020b), but this could not change the course of events (Ujvárosi and Halász 1952). It should be noted, however, that along with early stubble ploughing, the increased use of agro-chemicals and the emergence of a highly competitive new weed species, the common ragweed (*Ambrosia artemisiifolia* L.) could also have contributed to the decline of *S. annua*. Although in the 1960s, weed communities dominated by *S. annua* still endured in certain regions (Halmágyi and Suhayda 1966), they disappeared almost completely from Hungary by the end of the twentieth century together with its monofloral honey which became a rare honey delicacy (Kelemen 2009). Thanks to the reduction in the application of herbicides and fertilizers after the socio-economic changes around 1990, several rare weeds started to increase in the eastern European countries (Pinke 2020a). This also brought some optimism for the older generations of Hungarian beekeepers, who were hoping that *S. annua* would also make a comeback (Szalay 1993). However, this hope turned out to be in vain, and the dip in the general intensity of farming has also proven to be temporary. Even though scattered remnant stands still appeared occasionally (Pinke and Pál 2009), this plant eventually lost its relevance as a honey plant. This period also coincides with a general decline of diversity in the European weed flora due to agricultural intensification (Fried et al. 2009; Storkey et al. 2012; Richner et al. 2015; Pinke 2020a). In summary, the mean cover of *S. annua* reduced by about 90% even in uncultivated stubbles during the 60 years of this period (Novák et al. 2009).

In 2006, a new Hungarian governmental directive prescribed strict measures to control the allergenic ragweed (*A. artemisiifolia*), threatening noncompliant farmers with heavy fines. This initiated a third phase of decline for *S. annua*, as ragweed occupies the same stubbles (Pinke et al. 2011), and the new legislation has anticipated the timing and increased the intensity of stubble ploughing dramatically. This new invasive plant, therefore, exerts a strong negative impact on *S. annua* both directly (through biotic competition) and indirectly (through its effects on management). This dual impact coupled with climate change (causing more frequent summer drought periods), has ultimately stripped the Hungarian agricultural landscape of the last remaining *S. annua* flower carpets. The exceptional rainy summers, like the one of 2020, are now in vain. Farmers scared of administrative fines till their stubbles, including the rare sprouting stands of *S. annua*, in a hurry (Fig. 2b).

Prospects for revival

Although *S. annua* ceased to be a major or dominant species in Hungary, the species itself is not threatened yet, as it sporadically still exists in many places. In the Carpathian Basin, some larger dominant stands might still hide in Vojvodina (northern Serbia), where it is still listed among the main potential honey plants (Mačukanović-Jocić and Jarić 2016) and even its monofloral honey is occasionally still available (Fig. 2c). Nevertheless, *S. annua* honey and the related beekeeping practices can be regarded as a piece of cultural heritage shared by the people of the Carpathian Basin, irrespective of national boundaries. For example, beekeepers in various areas of Hungary (Arany et al. 2017) and Romania (Vári et al. 2017) still nostalgically remember this once important floral resource. The fact that there are still living memories and interest in this plant can possibly create a favourable environment to 'resurrect' this plant species with its high-quality honey and the related rich cultural heritage, too. As examples from France suggest, such socio-cultural 'drivers' can be of critical importance for the successful re-introduction of a traditional honey type (Lehébel-Péron et al. 2016).

Theoretically, there are two main options that would help to bring this species back from its recent decline. This would involve either strengthening its spontaneous populations or having to bring it into cultivation. However, both of these options come with a lot of difficulties. The protection of agricultural weeds is a notoriously complex and sensitive challenge, with many complex questions (Albrecht et al. 2016). The last few habitats where *S. annua* still massively emerges could be involved into targeted agri-environmental (Batáry et al. 2015) or 'eco-schemes'(Heyl et al. 2021) of the EU Common Agricultural Policy (CAP), to avoid their early destruction caused by stubble management. Within the frames of such programs, stubble tillage should be delayed up until September fifteenth of every year with the retention (and potential grazing) of cereal stubble weed communities as an alternative to catch crop or green cover plants. An involvement of beekeepers with hives placed next to the sites could also be prescribed. The most important site-selection criteria should be the abundance of *S. annua* and the absence of *A. artemisiifolia*. A moderate presence of invasive and allergenic weeds could also be controlled with targeted harrowing or mowing. Winter and, especially, spring cereals, as well as lacy phacelia (*Phacelia tanacetifolia* Benth.) are the most suitable crops to support the development of *S. annua*, particularly if less intensive farming practices are used (Pinke and Pál 2009; Pinke et al. 2020). Nonetheless, the intensity of flowering, nectar and seed production can still be fluctuating, depending on weather conditions. In addition, the emerging stubble community is initially hidden, and the success or failure of a program can only be observed after the harvest of the main (cereal) crop. These scenarios can make the site designations, the legal agreements, and the program management more complicated than it is in similar agri-environmental schemes.

Nevertheless, efforts for saving *S. annua* in the weed communities could also benefit other threatened species of the agroecosystems, and thus create hotspots for agricultural biodiversity. As was demonstrated in an earlier study, weed communities dominated by *S. annua* harboured other rare weed species, including important resources for wild pollinators (Fig. 3) and farmland birds (Pinke and Pál 2009). Accordingly, programs targeting stubble-flowers could also contribute to the conservation of the declining European arable weed flora (Meyer 2020), and consequently enhance the ecological multi-functionality of the diversity of the landscapes (Gaba et al. 2020). This includes sustaining pollinator assemblages between mass flowering crop periods (Bretagnolle and Gaba 2015; Requier et al. 2015; Rollin et al. 2016; Kovács-Hostyánszki et al. 2017; Venturini et al. 2017), and providing food source for farmland birds (Orłowski et al. 2011). The diversity of *S. annua* dominated weed communities can offer a diverse diet for wild bees, compensating the negative effects of monotonous diets from mass-flowering crops (Goulson et al. 2015). In addition, the main blossoming period of this type of vegetation overlaps with a critical "hunger gap" of bumblebees in August/September (Timberlake et al. 2019), when harrowed cereal stubbles and maize are not able to fulfil the demand of bumblebees' for pollen and nectar (Hass et al. 2019). A bee-friendly farming system (Decourtye et al. 2019; Cole et al. 2020; Storkey et al. 2020) yielding an eco-friendly honey can also increase public engagement in pollinator conservation (Hall and Martins 2020; Knapp et al. 2021). Stubbles can also encourage farmland bird populations, particularly

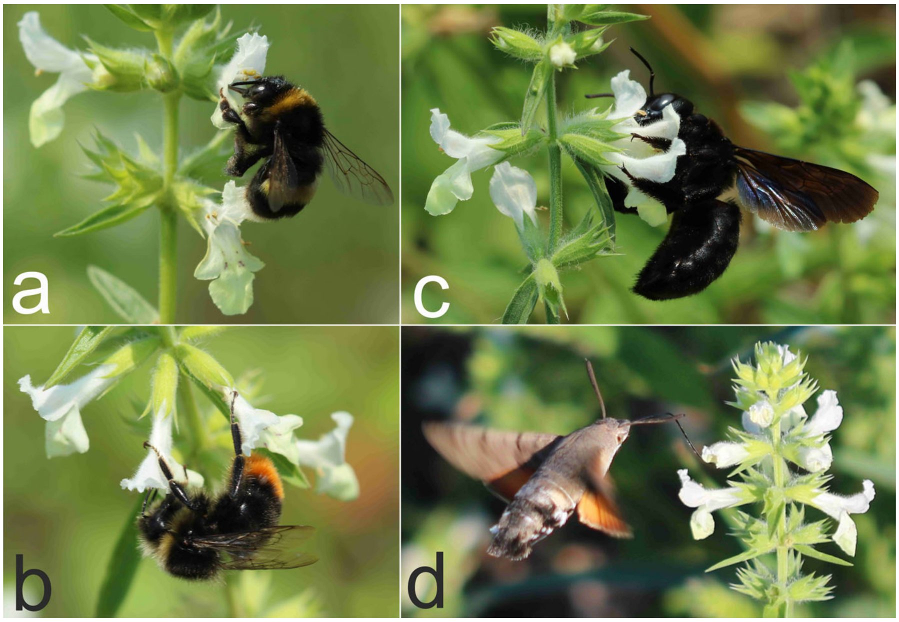

Fig. 3 Wild pollinator species foraging on *S. annua*. **a** *Bombus terrestris* L. (Buff-tailed bumblebee). **b** *Bombus lapidarius* L. (Red-tailed bumblebee). **c** *Xylocopa violacea* L. (Violet carpenter bee). **d** *Macroglossum stellatarum* L. (Hummingbird hawk-moth). (photo: Pinke G)

if they are still kept uncultivated until the winter (Orłowski et al. 2011), which provides an abundant source of weed seeds for the overwintering populations (Gillings et al. 2005). The oily seeds of *S. annua* themselves are a highly valuable food source for several bird species (Keve et al. 1953). The alarming decline of farmland birds in Central- and Eastern-Europe (Reif and Vermouzek 2019; Busch et al. 2020) further underlines the importance of an ecological stubble management.

A second potentially even more ambitious option for reviving *S. annua* is to establish it as a new multifunctional crop species. According to its history and ecological characteristics the species could be an ideal catch crop (or flower strip crop) in the ecological focus areas of the EU's greening programs (Pe'er et al. 2017), allowing for an increased green cover diversification. According to Garland et al. (2021), a diverse portfolio of such catch crops and cover crops can also significantly contribute to the conservation of soil multifunctionality. In Switzerland, for example, *S. annua* is already available as a component of seed mixtures to promote biodiversity in agro-ecosystems (Ramseier et al. 2016; Ganser et al. 2019). In Romania, Ion et al. (2018) recommended it for intercropping use, because of its short vegetation cycle and early flowering. The early crop experiments that took place in Hungary in the late nineteenth and early twentieth century could also support these initiatives with valuable lessons.

Transforming *S. annua* into a successful crop will not be an easy task, because there are several key bottlenecks that need to be overcome. This includes (i) the selection and breeding of stable varieties with high nectar flows and low seed dormancy, (ii) the elaboration of a technology for efficient seed production, and (iii) a massive branding challenge, where the people of the Carpathian Basin and Europe will have to be (re-)acquainted with this 'old/new' species and its high-quality monofloral honey. The seed dormancy of *S. annua* is a particularly important key challenge to be solved. The centuries of the three-field shifts have favoured and selected populations with a mean dormancy of 2–3 years. This dormancy must be removed from the seeds now, either by careful selection and breeding or through the development of appropriate seed treatments that artificially break it. The possible secondary uses of *S. annua*, particularly its seed oil, also offer both challenges and opportunities for the potential breeding programs and key topics for further scientific research.

In 2020, the present authors published many articles in Hungarian popular magazines to draw the attention of the public and decision makers on the declining trend and maintaining options of *S. annua* making way to the covers of several magazines (Fig. 4) (Pinke 2020b; Pinke and Dunai 2020; Pinke and Varga 2020). The authors also initiated a campaign "*Cooperation for saving the stubble-flower!*" among farmers and beekeepers (Pinke et al. 2020). With the support of a farmer and several beekeepers, they managed to retain the *Stachys*-rich weed community of a phacelia stubble of 20 ha in 2020, and successfully produced some 'stubble-honey' there (Fig. 5a), which was reported in a popular Hungarian beekeepers' magazine (Pinke et al. 2020). To continue with the experiments, dry plants were manually collected in the autumn for threshing the seeds (Fig. 5b–d), which are now followed by laboratory experiments to find out how to break the dormancy of the seeds, as well as cropping experiments in a conventional and an ecological farm. The investigation is equally aimed at developing an efficient seed harvest and threshing technology, in the hope that this work can lay the foundations for the successful (re)introduction of this prospective 'old/new' crop species.

Conclusions

Stachys annua is a once prominent, now rare characteristic plant species of the Carpathian Basin with multiple traditional uses and a fundamental role in the history of Hungarian apiculture. This species has suffered a dramatic decline during the last century which has led to the the disappearance of its unique honey from the market. Nonetheless, the species is still present both botanically and culturally in its former domain, and an active conservation and breeding program could potentially bring it back. A purposeful stubble retention in *S. annua* rich fields could not only alleviate the late-summer shortage of bee pastures but also benefit the declining farmland biodiversity, including wild pollinators and several endangered species of farmland birds. This in situ conservation could potentially be supported by targeted eco-schemes under the new EU CAP.

Furthermore, following a selection and breeding program, and the development of appropriate cultivation technologies *S. annua* could be turned into a successful crop species, which could find a niche as a prestigious bee forage plant suitable for intercropping, a catch crop, or even as an oil plant in the future. The greening efforts of the EU CAP create a high demand for such, low intensity multifunctional crop species. Nevertheless, the transformation of *S. annua* into a

Fig. 4 *S. annua* on the front cover of Hungarian popular magazines in 2020. The journals' titles from left to right: Life and Science, Beekeeping, Organic culture

Fig. 5 **a** A beekeeper with stubble honey still in the frames. **b** Manual "harvest" of *S. annua* plants for seed saving (Várbalog, northwest Hungary, September 2020). **c** Grinding the dried plants of *S. annua* (preparing for threshing). **d** Threshing. (photo: Pinke G)

successful crop species will still demand major efforts both in terms of plant breeding and scientific research.

Funding Open access funding provided by Széchenyi István University (SZE). The work of Gyula Pinke and Éva Dunai was supported by the EFOP-3.6.3-VEKOP-16- 2612017–00008 "Innovative Scientific Institutions in Domestic Agricultural Higher Education" project. The project is co-financed by the European Union and the European Social Fund.

Declarations

Conflict of interest The authors declare the absence of any conflict of interest.

Human and animal rights Human and animal rights were observed, and no animals or involuntary human participants were involved in this work.

Informed consent All authors provided an informed consent to the publication of this work.

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