Research Article

Crops gone wild – weedy *Helianthus annuus* L. in Austria

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Abstract

Weedy sunflowers can cause severe yield losses and have recently been reported in several regions of Europe. We present the results of a survey of 24 grid cells 1 km^2 in size on the distribution of weedy sunflowers in two different regions in Austria. Our results showed that weedy sunflowers (*Helianthus annuus* L.) occur in various crops (oil pumpkin, soybean, and maize). While most occurrences were small, a few fields were heavily infested (> 500 individuals) and weedy sunflowers reached cover values of up to 25%. The average number was 175 plants/km^2 across all grid cells surveyed, with an average of 324 plants/km^2 in the 13 infested grid cells and a maximum of approx. 1000 plants in the most heavily infested grid cell. The expression of recorded morphological traits (i.e., head number, height, and head diameter) varied considerably between populations of weedy sunflower, escaped sunflower, and cultivated sunflower. This study is the first to assess the infestation of weedy sunflowers in fields in Austria. We found evidence of the potentially substantial impact of weedy sunflowers on crop yields. Our findings highlight the need for further monitoring and controlling of weedy sunflowers in fields.

Key words: agriculture, Asteraceae, distribution, impact, spread

Introduction

Common sunflower (*Helianthus annuus* L., Asteraceae) is native to North America where it has been domesticated at least 4000 years ago (Harter et al. 2004). Nowadays, sunflower is cultivated worldwide and in Europe as an oilseed crop (Muller et al. 2011).

Sunflower occurs also as a weed in fields in the form of escaped sunflowers (so-called "volunteers"), which emerge from unharvested seeds of cultivated sunflowers in subsequent crops (Gillespie and Miller 1984; Snow 1999). Morphologically, they are closely resembling cultivated sunflowers. In recent decades, however, there have been increasing reports of weedy sunflowers occurring in fields in several parts of Europe (e.g., Muller et al. 2009; Kanatas et al. 2021; Stojićević and Vrbničanin 2022). Weedy sunflower populations are morphologically distinct from cultivated sunflower and escaped sunflowers. They show typical wild traits, such as anthocyanin pigmentation, extensive branching, reduced size of head and achenes, enhanced flowering time, seed shattering and seed dormancy (Muller et al. 2009; Presotto et al. 2011). Weedy sunflowers are highly competitive, can cause severe yield losses in a variety of summer field crops and thus, they are a weed management issue for farmers (Kanatas et al. 2021). Different scenarios for their origin were discussed (Muller et al. 2011). There is evidence that the weedy sunflower is the natural result of hybridization of wild sunflower with the cultivated sunflower (Casquero et al. 2013; Kanatas et al. 2021; Vercellino et al. 2023). Muller et al. (2011) reported that the weedy sunflower populations from southern Europe most likely originated from natural crop-wild hybrids (exoferality), i.e., due to the unintentional pollination of mother lines in sunflower seed production fields by wild sunflowers growing nearby. It is generally accepted that the weedy sunflower is not a separate subspecies of *H. annuus* (Kanatas et al. 2021).

In Austria, no study on the occurrence of weedy sunflowers has been done yet. However, anecdotal observations of the authors have shown that weedy sunflower populations have become established in several agricultural regions in the east and south of Austria. Thus, we established 24 grid cells 1 km^2 in size in two study regions of Austria and addressed the following research questions: 1) What is the distribution and abundance of weedy sunflowers? 2) What are the morphological characteristics of weedy sunflowers compared to escaped and cultivated sunflowers? 3) Which crops are affected by weedy sunflowers and what are the potential consequences for agriculture?

Materials and methods

In 2023, we established 24 grid cells 1 km^2 in size in two study regions of Austria, where the occurrence of weedy sunflower was known to the authors based on previous fieldwork (Figure 1). A brief description of the two study regions can be found in Table 1. The surveys in both study regions were conducted between July and September 2023.

The grid cells were randomly placed in both study regions (Figure 1), and all fields within them were surveyed for the occurrence of sunflower as a weed. Populations were identified as weedy sunflower based on characteristic morphological traits (Table 2). Populations that did not have these distinct traits and instead had similar characteristics to the cultivated sunflowers were categorized as escaped sunflowers (Table 2, Figure 2b, c). Another factor in the identification of escaped sunflowers was the even distribution in the field according to seed loss during harvest (Figure 2a). Each location of infestation was georeferenced and a map showing their spatial distribution was created based on the coordinates obtained.

To determine infestation levels and evaluate the agricultural impact of weedy sunflowers, crop type infested, and population size were counted for small infestations and estimated for large infestations. In addition, we recorded floristic relevés (n = 8) from different crop types infested by weedy sunflowers to characterize the floristic composition. Percentage ground cover

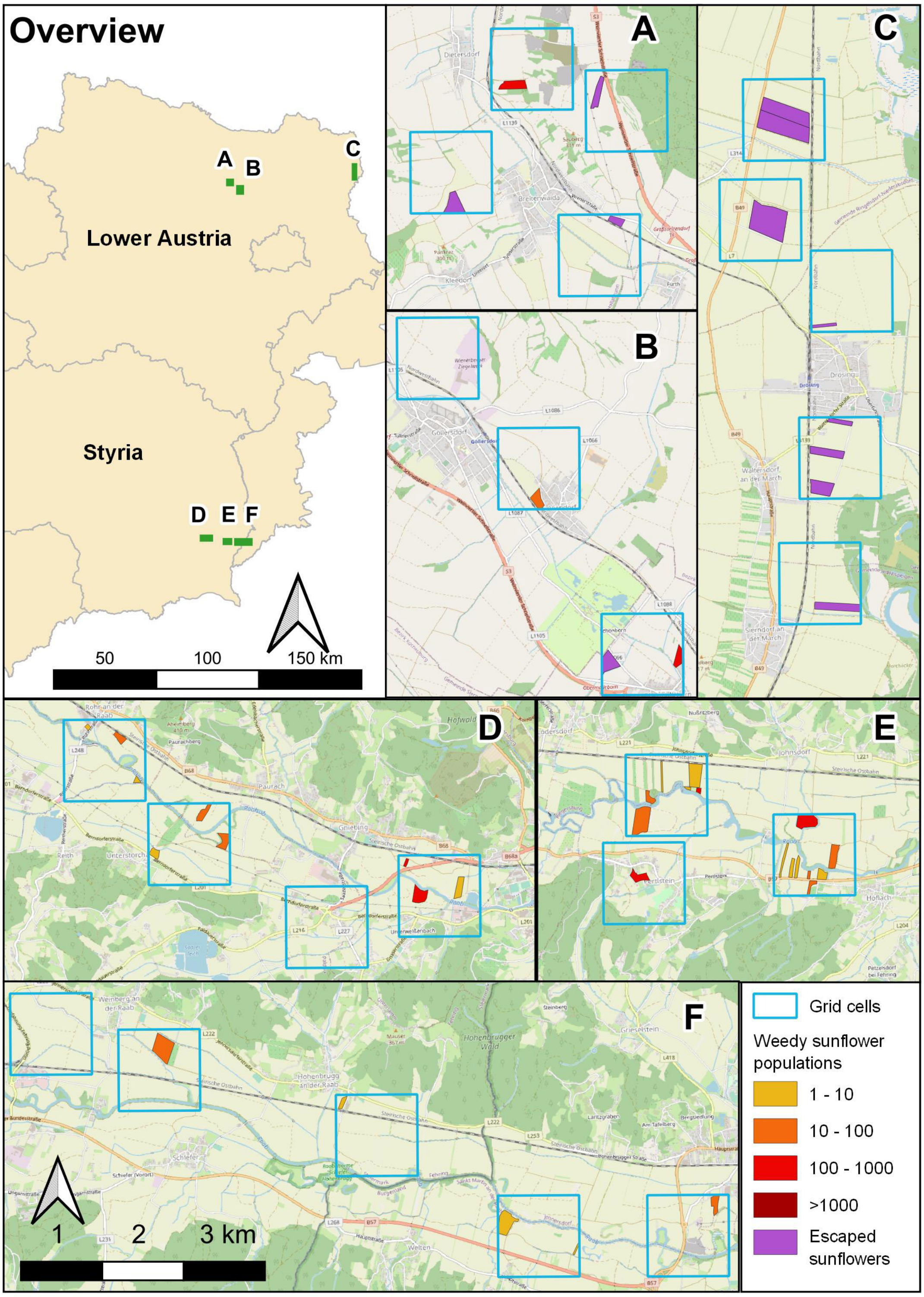

Figure 1. Maps of the locations of the study regions in Austria (overview) and of the 24 grid cells showing the distribution of weedy and escaped sunflowers in fields in northeastern (A to C) and in southeastern Austria (D to F) in 2023.

(0 to 100%) of each plant species in the plots was visually estimated (Andújar et al. 2010). Relevés of 100 m^2 in size were randomly established. This was either at the edge of the field or in the interior (Supplementary material Table S1), depending on the occurrence of the weedy sunflower. Botanical nomenclature followed Fischer et al. (2008) and POWO (2024) as well as the syntaxonomic classification Mucina et al. (2016).

Table 1. Overview of the two study regions: location, climate, and main crops.

Study region	Location	Climate	Main crops
1	Northeastern Austria (Lower Austria)	10.5 °C, 530 mm (Hohenau/March, 48.616389, 6.904389)	Cereals, sunflower, sugar beet, maize, oil pumpkin
2	Southeastern Austria (Styria)	10.2 °C, 760 mm (Feldbach, 46.948889, 15.879694)	Maize, oil pumpkin, soybean, cereals

Table 2. Overview of main distinguishing morphological traits between cultivated, escaped and weedy sunflower used in this study (adapted from Seiler 1997, Reagon and Snow 2006, Stojićević and Vrbničanin 2022).

Trait	Cultivated sunflower	Escaped sunflower	Weedy Sunflower
Head number	1	1 to several	Numerous
Head diameter	Uniform in the crop stand (15 to 30 cm)	Uniform to variable in the crop stand (15 to 30 cm)	Small (less than 10 cm)
Plant height	Uniform in the crop stand (120 to 180 cm)	Uniform to variable in the crop stand (120 to 200 cm)	Variable and can be very high (up to 250 cm)
Branching	No branching	No branching to apical branching	Full branching

In both study regions, three distinct parameters (number of heads, first head diameter, height) of 10 randomly chosen individuals in selected weedy sunflower populations (n = 13) were recorded for morphological characterization (Stojićević and Vrbničanin 2022). Data from randomly selected populations of cultivated sunflowers (n = 8) and escaped sunflowers (n = 6) were collected for comparison. The analyses were performed in R version 4.3.0 (R Core Team 2023). We conducted a hierarchical cluster analysis (method ward D; Murtagh and Legendre 2014) to assess the morphological similarities among the studied populations and assign them to subgroups. We used the Kruskal-Wallis test to compare different clusters and we applied the Siegel and Castellan test, which is implemented in the R package pgirmess (Giraudoux 2023), for post-hoc analysis.

Results

Distribution and abundance

In total, 32 populations of weedy sunflowers have been recorded in 13 out of the 24 grid cells that were surveyed in 2023 (Figure 1). Populations of weedy sunflowers were observed in both study regions, although they were more frequently detected in Styria (n = 29) than in Lower Austria (n = 3). A further 12 populations of escaped sunflowers were recorded exclusively in north-east Austria (Figure 1). In three grid cells, no sunflower infestations have been found at all. The number of infested fields by weedy sunflowers in the grid cells ranged from one to eight. In most infested fields (80%), total population size of weedy sunflowers was small to medium (< 100 individuals). However, large infestations have been recorded in a few fields with more than 500 individuals and there dense, large clusters have been recorded, indicative of a severe infestation. The average number of weedy sunflowers was 175 plants/km^2 across all grid cells surveyed, with an average of 324 plants/km^2 in the 13 infested grid cells and a maximum of approx. 1000 plants in the most heavily infested grid cell. In our study, in 2023, weedy

Figure 2. Images from escaped and weedy sunflowers in Austria: Escaped sunflowers (a) closely resembling the cultivated sunflower with one single large head in oil pumpkin and (b), (c) with head formation in the upper part in oil pumpkin and potato, respectively. Weedy sunflowers in oil pumpkin (d, e) and in cultivated sunflower (f, g) showing distinct characteristics, i.e., plant height, strong and deep branching, multiple heads, discoloration of heads and stems (anthocyanin accumulation). ©Swen Follak, Franz Essl.

sunflowers were most frequently recorded in oil pumpkin (42% of populations), followed by soybean (30%), and others (maize, sunflower, potato, etc.). We believe that the populations can be classified as weedy sunflowers, as most of them were found in southeastern Austria (Figure 1), where sunflower is almost not cultivated at all. Moreover, populations differed morphologically from cultivated and escaped sunflowers; therefore, they cannot be traced back to seeds from sunflowers cultivated in previous years.

Table 3. Floristic composition of relevés with occurrences of weedy sunflowers in Austria. Relevés were from soybean (1, 3, 6), oil-pumpkin (2, 4, 8) and maize (5, 7). Percentage ground cover (0 to 100%) of each species was visually estimated. For information on geographic coordinates and site characteristics, see Table S1.

Relevés No.	1	2	3	4	5	6	7	8
Vegetation cover	98	98	100	97	100	100	99	95
***Helianthus annuus* (L.)**	5	0.5	2	7	20	1	2	25
Acer pseudoplatanus L. (juvenile)	.	.	.	.	.	0.1	.	.
Ailanthus altissima (Mill.) Swingle (juvenile)	.	.	.	.	.	0.2	0.1	.
Amaranthus powellii S. Watson	.	.	.	.	.	.	.	0.5
Amaranthus retroflexus L.	.	0.2	0.3	.	25	.	.	.
Ambrosia artemisiifolia L.	.	.	.	.	5	.	0.5	.
Atriplex patula L.	.	.	.	2	.	.	.	.
Bidens tripartita L.	.	.	0.3		.	.	.	.
Calystegia sepium L.	.	7	10	15	20	1	8	30
Capsella bursa-pastoris (L.) Medik.	0.2	.	.	.	.	.	.	.
Chenopodium album L.	3	5	0.1	0.2	0.3	0.1	.	8
Chenopodium hybridum L.	.	.	.	.	.	.	.	0.5
Chenopodium polyspermum L.	.	3	.	15	0.5	0.1	.	7
Cirsium arvense (L.) Scop.	.	.	0.3	.	0.5	.	.	.
Convolvolus arvensis L.	2	.	0.2	.	.	0.1	.	.
Cucurbita pepo L. (cultivated)	.	70	.	90	.	.	.	100
Digitaria sanguinalis (L.) Scop.	.	0.2	.	.	.	.	0.2	.
Echinochloa crus-galli (L.) P. Beauv.	0.5	0.2	15	.	0.2	2	1	.
Elymus repens (L.) Gould	.	0.2	2	.	.	0.1	0.1	0.1
Equisetum arvense L.	.	0.5	3	2	0.2	0.1	.	0.5
Galinsoga parviflora Cav.	.	.	.	0.2	0.5	.	.	.
Glycine max (L.) Merr. (cultivated)	95	.	97	.	.	100	.	.
Lolium perenne L.	.	.	.	.	.	.	0.2	.
Matricaria chamomilla L.	.	.	.	.	.	.	0.1	.
Mercurialis annua L.	0.5	.	.	.	.	.	.	.
Panicum dichotomiflorum Michx.	.	.	.	.	.	.	0.7	.
Panicum miliaceum ssp. *ruderale* (Kitag.) Tzvelev	.	.	.	.	.	.	.	1
Persicaria lapathifolia (L.) Delarbre	7	60	0.2	3	0.2	0.1	1	0.1
Persicaria maculosa Gray	.	.	.	.	.	.	0.5	.
Potentilla anserina L.	.	.	0.2	.	.	.	.	.
Salix alba L. (juvenile)	.	.	.	.	.	0.1	.	.
*Setaria pumila (*Poir.) Roem. & Schult.	.	.	5	.	.	.	.	.
Solanum nigrum L.	.	.	.	.	.	0.1	.	.
Stellaria media agg.	2	.	.	.	0.1	.	.	.
Symphytum officinale L.	.	.	0.2	.	.	.	.	.
Taraxacum sect. *Taraxacum* F.H.Wigg.	.	.	.	.	0.2	0.1	.	.
Zea mays L. (cultivated)	.	.	.	.	85	.	97	.

Floristic characterization

The documented weed communities belong to the class *Digitario sanguinalis-Eragrostietea minoris* Mucina, Lososová et Šilc in Mucina et al. 2016 (Mucina et al. 2016) (Tables 3 and S1), which is widespread in the lowlands of temperate Central Europe (FloraVeg.EU 2023). The most frequent species were *Chenopodium album* L., *C. polyspermum* L. *Persicaria lapathifolia* (L.) Delarbre, *Calystegia sepium* L., *Amaranthus powellii* S. Watson, *Amaranthus retroflexus* L. and panicoid grasses (*Echinochloa crus-galli* (L.) P. Beauv, *Digitaria sanguinalis* (L.) Scop.) as well as *Elymus repens* (L.) Gould. The frequent occurrence of weedy sunflowers together with species preferring well-watered sites like *C. sepium* (cover values up to 30%), *P. lapathifolia* and

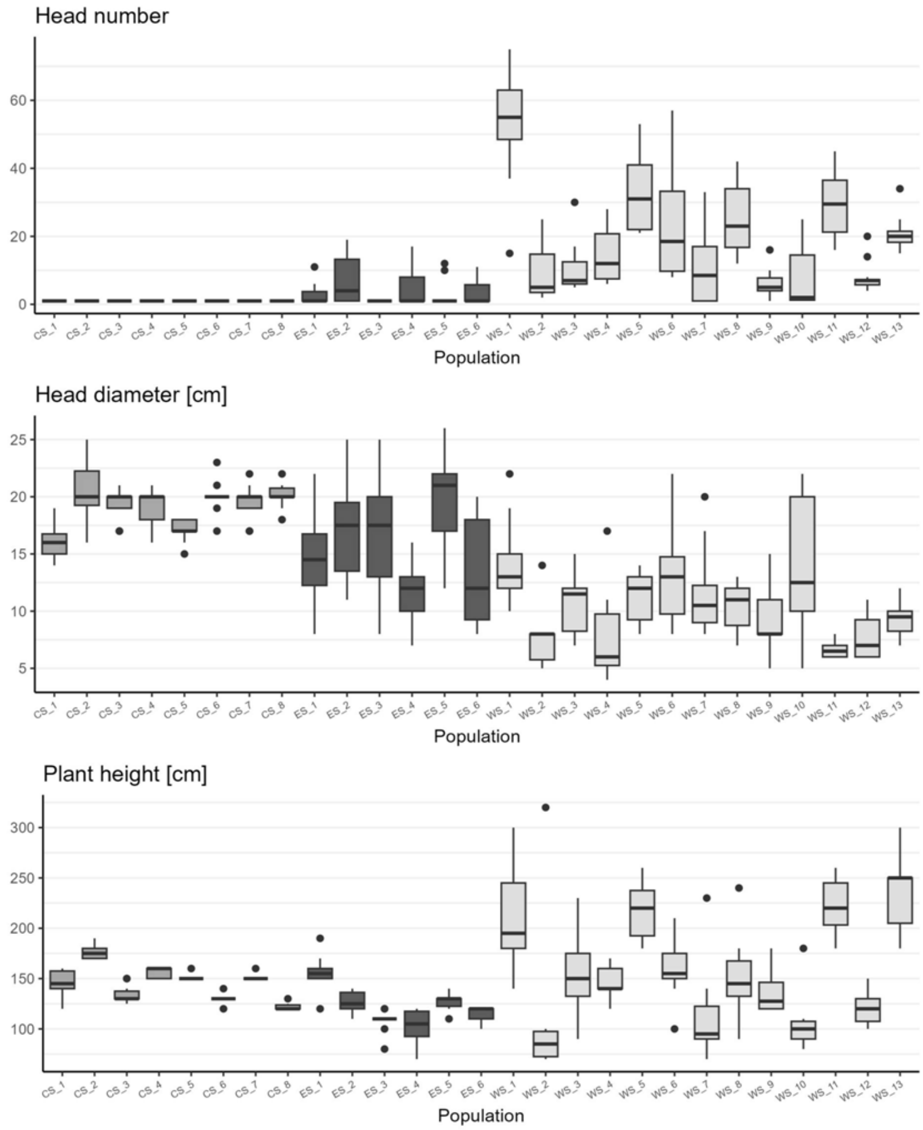

Figure 3. Morphological traits of ten randomly chosen individuals of 27 studied sunflower populations. Head number, first head diameter and plant height and the median value and interquartile range are shown. CS = cultivated sunflower, ES = escaped sunflower, WS = weedy sunflower.

Equisetum arvense L. is likely due to the loamy, temporarily wet soils (proximity to the river Raab) in study region two (Styria) (https://bodenkarte.at). Juvenile tree species (e.g., *Salix alba* L., *Acer pseudoplatanus* L.) were also found in individual fields, which were located close to riparian vegetation. In the fields surveyed, cover values of *H. annuus* were between 0.5 to 25%. Highest cover values recorded in the plots were 5% in soybean, 20% in maize and 25% in oil pumpkin.

Morphological characterization

The results showed that the sunflower populations studied differed morphologically from one another (Figure 3, Table S2), and thus, populations were assigned into three clusters (Figure 4). Statistically significant differences were observed between the clusters in terms of head diameter (p = 0.000057),

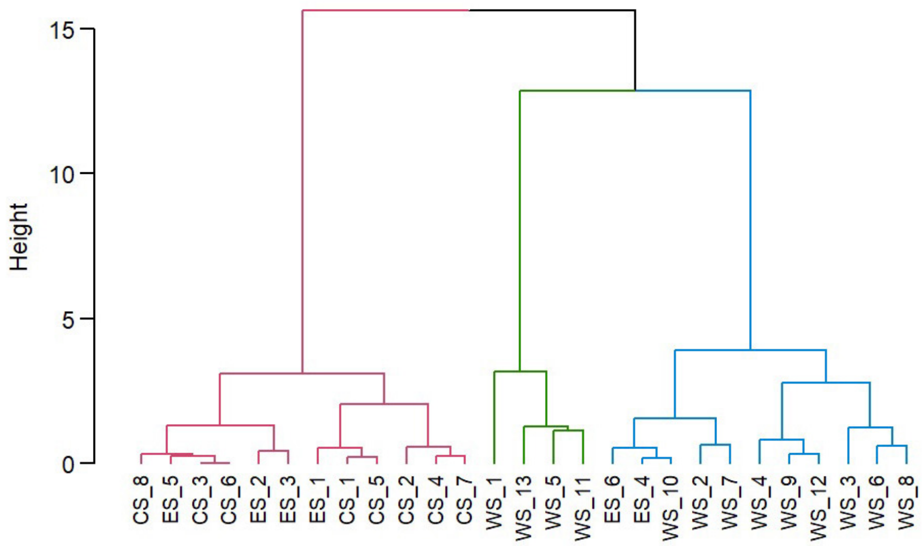

Figure 4. Cluster dendrogram of the studied sunflower populations (n = 27) based on morphological traits (head number, first head diameter, plant height) of ten randomly chosen individuals. CS = cultivated sunflower, ES = escaped sunflower, WS = weedy sunflower.

number of heads (p = 0.000067), and height (p = 0.002). Weedy sunflower populations showed substantial variability in morphological traits (Figure 3) and were thus categorized into two clusters (Clusters 2 and 3, Figure 4). Four populations of the weedy sunflower (WS_1, WS_5, WS_11, WS_13) were in cluster 2. They showed distinct morphological traits with extreme heights (median > 195 cm), many heads (median > 20), and small head diameters (median 6.5 to 13 cm) (Figure 2d–g). The plants in this cluster were statistically significantly taller than those in clusters 1 and 3.

Populations of cultivated and escaped sunflowers were assigned to a separate cluster. Cultivated sunflowers had unbranched stems that were topped by a single, large-diameter head, with a height between 120 and 175 cm (Figure 3). Escaped sunflowers typically had a similarly sized head and plant height resembling the cultivated sunflower, while some also showed branching but only in the upper third of the stem (Figure 2b, Figure 3 e.g., ES_2). Cluster 1 has statistically significantly higher head diameters and fewer heads than the other two clusters. Two of the populations (ES_4 and ES_6) classified as escaped sunflowers were assigned to cluster 3 together, with weedy sunflower populations.

Discussion

Distribution and abundance

In the present study, the regular occurrence of weedy sunflowers was demonstrated in two study regions in Austria. Populations were mainly scattered across the surveyed grid cells and there was no large-scale infestation in the study regions. In fact, infested fields were found next to completely uninfested fields. A few large infestations of weedy sunflowers were found only in parts of southeastern Austria (Figure 1E), indicating geographical clustering and localized dispersal from field to field. Escaped sunflowers were exclusively recorded in northeastern Austria, which was expected because sunflowers are cultivated on a large scale in this region. In a recent study, Pinke et al. (2024) showed that potato fields in eastern Austria were regularly infested by sunflower, which is consistent with our observations (Figures 1c, 2a–c). However, information on which weedy form was present was not provided (i.e., escaped vs. weedy sunflower).

In both study regions, weedy sunflower infests a variety of spring crops as shown by the relevés, such as oil pumpkin, soybean, maize, and cultivated sunflower. Most fields were infested by only a few individuals, whereas single fields were more severely infested (> 500 individuals), and high cover values (up to 25%) were recorded. This was especially the case for low-growing crops such as oil pumpkin and soybean (Figure 2). Weed control in oil pumpkin is more challenging than in other crops, as there are only a limited number of registered herbicides applicable, and its growth habit makes mechanical control difficult (Pinke et al. 2018). Maize was also infested (Table 3). In general, sunflowers can be successfully controlled by using herbicides in maize. However, some of the standard herbicides used have efficacy gaps that may have led to control failures.

The occurrence and abundance of weedy sunflowers in neighboring and other European countries indicate that the species has adapted to a variety of environments. In the Czech Republic, Holec et al. (2005) reported few infestations in sunflower fields that were mainly scattered in the field margins, with some infestation clusters in the inner part of the fields. In France and Spain, there was also no geographical clustering of infested fields in any of the regions surveyed, and heavily infested fields were found in only a few cases (Muller et al. 2009). However, in other countries, weedy sunflowers are already much more widespread (Stojićević and Vrbničanin 2022). In Serbia (Vojvodina, Belgrade area), weedy sunflowers infest maize, sugar beet, cultivated sunflower, and cereals. The authors reported that weedy sunflower occurred at almost 200 sites in these crops with severe infestations at some sites with populations of more than 100.000 individuals and 20 to 30 plants/m^2. No weedy sunflowers were observed outside the fields during our survey. In the countries specified above, this species also occurs in ruderal plant communities along roads, canals, and on uncultivated land (e.g., Stanković-Kalezić et al. 2007; Muller et al. 2009).

Morphological characterization

Research has shown that weedy sunflower populations have a variety of phenotypes that form a continuum between wild ecotypes and cultivated morphotypes, i.e., plants combine domesticated and wild traits in varying proportions (Muller et al. 2011; Saulić et al. 2013; Kanatas et al. 2021). This can also be seen in the weedy sunflower populations described in our study, as the expression of the traits studied varied considerably and populations were categorized into two clusters. The populations in cluster 2 showed the most distinct wild-type traits. They strongly phenotypically resembled the weedy sunflower types described by Stojićević and Vrbničanin (2022) and Muller et al. (2009) from Serbia and France/Spain, respectively. In Serbia, this species has been spreading for more than two decades and populations with these characteristic traits have developed over time (Stojićević and Vrbničanin 2022). Cluster 3 comprises weedy sunflower populations with less pronounced wild-type traits, with some of them closely resembling escaped sunflowers. According to Muller et al. (2009), however, weedy sunflowers are morphologically different from escaped sunflowers, arising from the segregation of cultivated varieties. In this respect, the collection of further traits (e.g., anthocyanin pigmentation, other generative parameters, such as seed dormancy) would enable a more precise description and differentiation of Austrian populations.

Agricultural impact, implications for management and further research

Sunflower (i.e., escaped and weedy sunflower) is a highly competitive species, which is attributed to its early season vigor, high growth rates, biomass accumulation, and plant height (Geier et al. 1996). Quantitative data on yield losses due to sunflower infestation have been summarized by Kanatas et al. (2021) and range from 27% to 97% depending on sunflower density, crop type, and location. For example, in France, Muller et al. (2009) showed substantial yield losses of up to 60% of cultivated sunflowers in competition with 12 to 15 weedy sunflower plants/m^2.

Thus, it is important to monitor weedy sunflower populations in Austria to better assess their establishment and spread (Muller et al. 2009; Stojićević and Vrbničanin 2022). In particular, high seed production and seed shattering allow the build-up of large seed banks and the rapid spread of infestations within fields. The present study indicated that a few individual fields were already heavily infested, and that significant yield losses were expected. Therefore, effective control of weedy sunflowers and of escaped sunflowers is essential to avoid spread, yield losses, and further crop-weed gene flow. Management options have been compiled by Kanatas et al. (2021) and include preventive measures, cultural practices, herbicide use, and mechanical methods.

The reasons for the occurrence of weedy sunflower populations in the study regions cannot be clarified in our study, that is, whether they have evolved *in situ* or have been introduced as seed contaminants (Muller et al. 2009; Kanatas et al. 2021). Their emergence may also be the result of hybridization of ornamental sunflower cultivars, which are commonly grown in gardens in the regions studied, with cultivated sunflower in fields (or escaped sunflowers) (Faure et al. 2002; Muller et al. 2011). In this respect, the analysis of the genetic diversity can provide further information (Muller et al. 2011).

Authors' contribution

SF and FE conceived the study, conducted the field surveys and data collection. SF and FE wrote the manuscript. MG produced the map and AG did the data analysis. All authors reviewed the manuscript.

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Supplementary material

The following supplementary material is available for this article:

Table S1. Site characteristics

Table S2. Morphological traits of *Helianthus annuus* L.

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