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The segetal flora of *Cynara cardunculus* L. (globe artichoke) fields in Sardinia

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Abstract
The aim of the present study was to produce a first inventory of the segetal flora in *Cynara cardunculus* L. (globe artichoke) cropping systems in Sardinia (Italy), to address the limited research available to date, despite the economic significance of this crop. Field surveys were conducted during 2019–2021, at least three times per year, to assess the segetal flora and its main specific features (e.g., life forms, chorology and invasive status in Sardinia), using randomly located georeferenced plots (1 × 1 m) within each field. Based on floristic surveys, it was possible to make an inventory of 113 taxa classified into 91 native species of the Italian flora, 1 archaeophyte, 5 cryptogenic and 16 neophytes, of which 11 were invasive in Sardinia, four naturalized and one casual. Among identified species, 83 were therophytes, 23 hemicryptophytes, 6 geophytes, and 1 chamaephyte. The chorological spectrum shows up the dominance of Mediterranean with 52 species. Widely distributed taxa are represented by 20 species, followed by Eurasian ones with 9 taxa. The most frequent and abundant species were the three native *Calendula arvensis* (Vaill.) L., *Convolvulus arvensis* L., and *Lolium rigidum* Gaudin, the archaeophyte *Avena fatua* L. s.l., and the two neophytes *Oxalis pes-caprae* L., and *Veronica persica* Poir.

Keywords
Agroecosystems, arable plant, floristic inventory, Mediterranean Basin, weeds, neophytes

Introduction

The perception of weeds is highly subjective, embedded in human perspectives on plant diversity (Martín-Forés et al. 2017). A plant may be considered a weed if it disrupts human activities, leading to the categorization of agricultural, ruderal, grassland, and forestry weeds. Plants classified as weeds in arable land, typically annuals, are specifically referred to as agrestals or segetals (Holzner 1982). Such species grow in agroecosystems amongst crops, and their composition and biomass depend on both environmental conditions and agricultural management (Holzner and Numata 2013). Typically, segetal flora is composed of native and non-native species (archaeophytes, neophytes and cryptogenic) and it may include cultivated species persisting for short periods as ephemeral or casual among rotation cycles. Importantly, archaeophytes are a uniquely interesting group of plants, often regarded as "cultural relics" that track the transition in human history from nomadic, hunter-gatherer communities to settled agricultural activities. Species such as *Agrostemma githago*, *Silene linicola*, and *Turgenia latifolia* have either nearly vanished from Europe or become rare (Fried et al. 2009; Comin and Polidini 2010).

The management of segetal flora represents one of the major critical issues for crop systems, due to the competition it exerts for water, mineral nutrients and light, sometimes compromising quantitatively and qualitatively agricultural production or requiring the use of plant protection products (Fanfarillo et al. 2020c). Moreover, many weeds have traits that make them aggressive towards cultivated species and difficult to contain in agricultural systems (Kumar et al. 2024). However, some studies have emphasized the ecological and agronomic advantages of segetal species since their presence could increase the biodiversity of agroecosystems, supporting pollinators, preserving genetic resources, regulating pests, and protecting soil (Marshall et al. 2003; Storkey and Neve 2018). In addition, Adeux et al. (2019) addressed that species-rich segetal communities can reduce crop yield losses, decreasing the probability of occurrence of dominant and competitive species that aggressively compete with crops. Segetal diversity promotes ecological and functional equilibrium, showing that not all weeds are detrimental to crop productivity.

The intensification of agricultural practices, reduced crop rotation, deep tillage, intensive use of fertilizers, landscape simplification, abandonment of low-productivity sites, and chemical weed control have caused significant changes in the segetal flora. The aforementioned factors reduce the biodiversity of the segetal flora by favoring a few highly competitive species and promoting the spread of neophytes and herbicide-resistant plants. This results in a reduction in the richness of native species and alteration in the floristic composition of segetal plant communities (Storkey et al. 2012; Pannacci et al. 2018; Storkey and Neve 2018). In fact, Fanfarillo et al. (2019) show that neophytes can reduce native species' richness and alter the floristic structure in maize fields in Latium (IT). They also observed a species turnover, where some native taxa and archaeophytes were displaced by neophytes. This change indicates a homogenization trend driven by modern agricultural treatments.

In conventional crop systems, the containment of weeds is often performed with the total or almost total elimination of weeds, through direct and indirect control methods. Indirect methods aim to prevent weed infestations, while direct methods aim to eradicate the weed flora through mechanical weeding (weeding, harrowing and milling) or chemical methods using synthetic herbicides. The influence of crop rotation on the composition and abundance of segetal flora has been frequently investigated, highlighting its effectiveness in limiting the spread of aggressive weed species (Bond and Grundy 2001; Hosseini et al. 2014). In contrast, incorporating cover crops has been shown to suppress weed growth, decrease seed survival and germination, maintain seed dormancy, and simultaneously enhance soil fertility (Sias et al. 2021). Then, a successful long-term strategy for sustainable weed control and containment in agroecosystems hinges on the effectiveness of the various available control methods (van der Weide et al. 2008).

Cynara cardunculus L. (globe artichoke) is an important horticultural perennial herb belonging to the Asteraceae family, resulting from human selection pressure of wild ancestors, native to the Mediterranean Basin (Sonnante et al. 2007; Gatto et al. 2013). The cultivation of this crop is particularly relevant in the Southern European regions, which holds 40% of world production (Martin et al. 2016; Shinohara et al. 2017; Nouraei et al. 2018), and in recent years in the Americas and China (Scaglione et al. 2016). The growing cycle may be both multi-annual or annual depending on the varietal type and cultivation area (Calabrese 2009). Specifically, the planting of the Sardinian spiny artichoke crop (cv Spinoso sard') takes place in the summer months between June-July (northern Sardinia) and August (southern Sardinia), with the aid of sprinkler or drip irrigation. This planting technique (forcing) makes this crop particularly subject to competition by different weed species in the young post-emergence stages. However, some laboratory surveys demonstrated the ability of artichoke to inhibit seed germination and seedling growth in several weed species, through allelopathic effects (Scavo et al. 2018, 2019c).

The aim of the present study is to provide a first inventory of the segetal flora found in artichoke fields in the island of Sardinia (Italy). In fact, despite the economic value of this crop, there are only a few studies on the segetal flora of artichoke fields (Fracchiolla et al. 2022; Scavo et al. 2019, 2024; Tiloca et al. 2024).

Materials and methods

Study area

The research was conducted in Sardinia, Italy, the second largest island in the Mediterranean basin (24,100 km^2), in four farms located across a north-south gradient, in the following 4 Sardinian localities: Villasor (39.375°N, 8.641°E); Cabras (39.952°N, 8.565°E); Uri (40.623°N, 8.471°E) and Valledoria (40.915°N, 8.851°E) (Fig. 1A). According to the Sardinia soil map (see Vacca et al. 2014), the pedological characteristics are characterized by alluvial soils found on extensive flat surfaces. These soils are generally deep, with textures ranging from sandy loam to clay loam (e.g., Villasor and Cabras). However, in Cabras, the presence of clayey horizon layers reduces permeability and increases the risk of flooding. At Valledoria the soil is sandy and deep, of aeolian and alluvial origin and at Uri the soil textures vary from sandy loam to clay, often of medium or reduced depth (Pisanu et al. 2009). The climate is characterized by two main seasons, a hot-dry season and a cold-humid one. Annual mean temperature

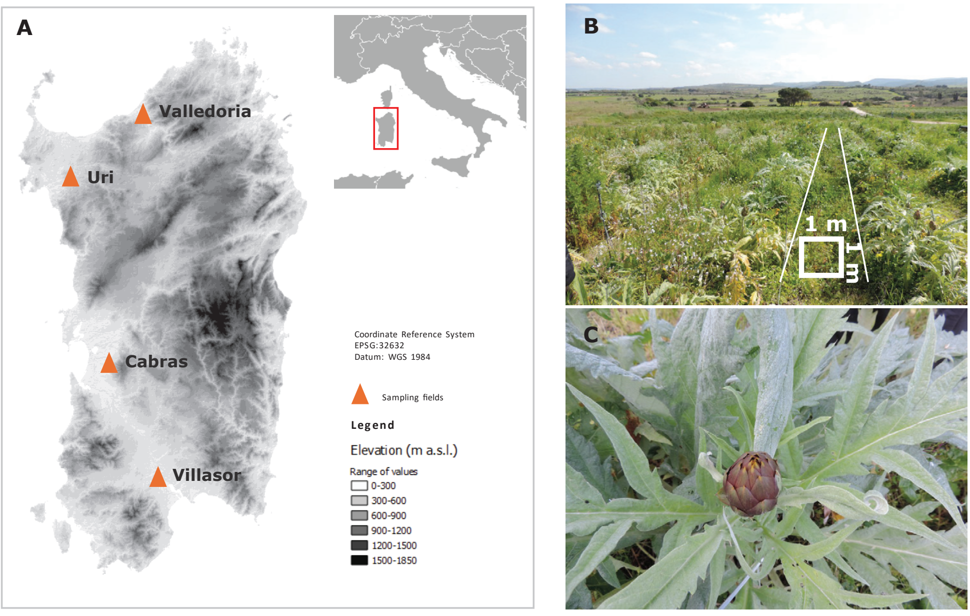

Figure 1. The figure shows **A.** The elevation map (derived by the 10 × 10 m DEM- Digital Elevation Model - of Sardinia) with the study area located on the island of Sardinia (Italy) and the fields surveyed in this study are represented by orange triangles. Created using QGIS (v. 3.12.2-București) software QGIS Development Team (2022); **B.** The *Cynara cardunculus* L. (globe artichoke) cropping system and **C.** A globe artichoke plant.

ranges from 17 to 18 °C on the coast to 10–12 °C on the inland mountains. Annual precipitation varies greatly from the coast to the inland, from around 433 mm y−1 in the southern coast to 1412 mm y−1 in the North at 1000 m a.s.l. (Arrigoni 2006–2015). In addition, a summer period of aridity, with low precipitation, marks the typical Sardinian bioclimate Mediterranean pluviseasonal-oceanic (Rivas-Martinez and Rivas-Saenz 1996–2019). Sardinian flora comprises 2,482 native species (Bartolucci et al. 2024). A more recent study established that the island is home to 341 endemic plant taxa, representing approximately 14% of the total native flora (Fois et al. 2022). Due to this high endemicity rate, Sardinia has been classified as a meso-hotspot of plant diversity within the broader macro-hotspot that encompasses Tyrrhenian continental islands in the central-western Mediterranean, together with Corsica, Sicily, Balearic and Tuscan Archipelagoes (Cañadas et al. 2014).

Data collection

Field surveys were carried out over three artichoke growing seasons each year between 2019 and 2021 (i.e., between mid-May, early July, and the end of October). For each of the four selected artichoke farms, interrow were randomly sampled (i.e., surveyed plots for each season and for each year were different to maximize the number of recorded species) (Fig. 1A). At each field, a total of 12 plots of 1 × 1 m size was surveyed (Fig. 1B). For each plot the presence of all plant species was recorded. Seasonal sampling over three consecutive years was essential to account for the temporal variability in species emergence throughout the crop period, as a single survey would fail to capture the full floristic diversity present at different phenological stages. Furthermore, seasonal sampling was necessary because therophytes complete their life cycles and produce mature seeds at different times of the year.

Species nomenclature follows Bartolucci et al. (2024) for native species and Galasso et al. (2024) for non-native species. The systematic order and taxonomic constraint of the families follow the classification proposed by APG IV (2016) for angiosperms. It was also compiled, based on the descriptions in the national flora, the life forms of the species based on the position of the permanent buds in relation to the soil surface during the unfavorable season (Raunkiaer et al. 1934) as follows: chamaephytes (Ch), hemicryptophytes (H), geophytes (G) and therophytes (Th). Life forms and chorology was compiled according to Pignatti et al. (2017–2019). The invasive status of the species in Sardinia was classified according to the portal to the flora of Italy (https://dryades.units.it/floritaly) in the following categories: (1) native; (2) archaeophyte; (3) cryptogenic, and (4) neophyte.

Results

Overall, during this three-year study, 113 taxa from 31 families were recorded in the 384 plots located in the four artichoke fields in Sardinia. The full list is reported in Suppl. material 1 and follows angiosperm phylogeny classification of flowering plants (APG IV) with families organized alphabetically. All taxa recorded in the inventory are angiosperms. The families with the highest number of species were Asteraceae (21), Poaceae (15), and Fabaceae (11), followed by Brassicaceae (6) (Fig. 2). The genera represented most were *Amaranthus* (3), and *Medicago* (3). Among monocots, 17 taxa were found to be distributed in three different families (15%), while the remaining 96 (85%) taxa belongs to the clades Asterids (49), Eudicots (6), Rosids (28) and Superasterids (13).

The segetal flora contains 91 species native to the Italian flora, 1 archaeophyte, 5 cryptogenic and 16 neophytes, of which 11 were invasive in Sardinia, four naturalized and one casual. Out of the total species identified, 83 were annual species (therophytes), 23 were hemicryptophytes, 6 geophytes, and 1 chamaephyte (Fig. 3). The chorological spectrum shows up the dominance of Mediterranean species (52). Widely distributed taxa are represented by 20 species, followed by Eurasian ones with 9 taxa (Suppl. material 1).

Discussion

This inventory is the results of three-year field surveys, aiming to fill a knowledge gap. In fact, despite recent efforts to compile comprehensive lists of weeds in cultivated areas and irrigated crops on the island of Sardinia, through field studies and bibliographic research (Viegi 1993; Cossu et al. 2014), and lists of non-native species in irrigated Mediterranean orchards (Juárez-Escario et al. 2012), a significant knowledge gap remains for certain agroecosystems and for economically important crops, such as artichokes.

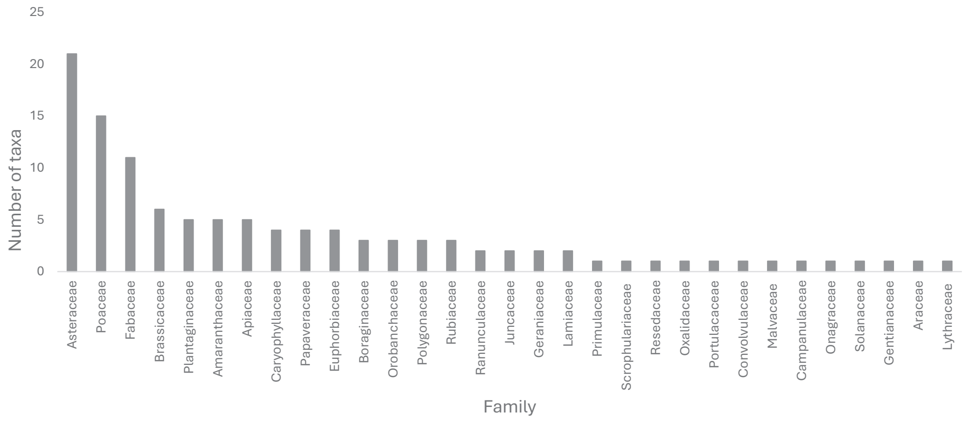

Figure 2. Families ordered according to the number of taxa they comprise in the segetal flora of globe artichoke cropping systems.

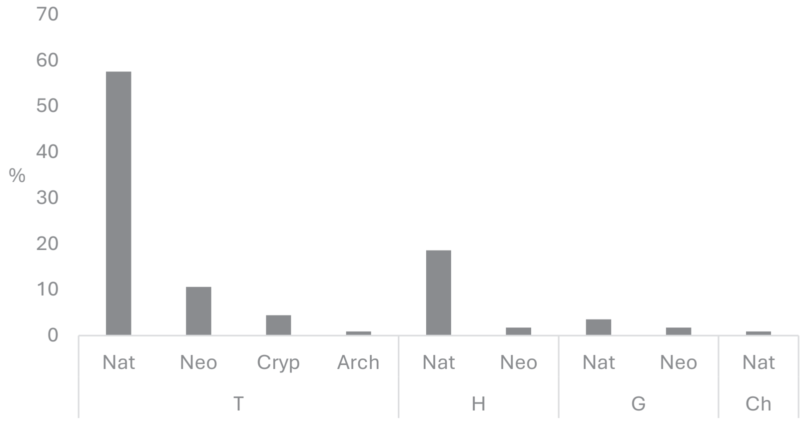

Figure 3. Percentage of species related to their Raunkiaer's life form i.e., Ch = chamaephyte; G = geophyte; H = hemicryptophyte; T = therophyte and by their biogeographical status i.e., Arch = archaeophyte, Cryp = cryptogenic; Nat = native; Neo = neophyte.

This first comprehensive inventory of the segetal flora of globe artichoke fields contains 113 vascular plants of which the majority are native species (80.5%). This list of species is the most comprehensive effort to date to catalog the segetal species found in globe artichoke fields, accounting for 12% of the total taxa within the segetal habitats in Italy (Fanfarillo et al. 2020c). The families most prevalent corresponded to those identified in the checklists of both native and non-native floras of Italy, with Asteraceae, Fabaceae, and Poaceae containing the greatest number of taxa (Bartolucci et al. 2024; Galasso et al. 2024).

The plant species found in the artichoke fields often extend their range to other segetal habitats in Italy, such as winter cereal fields (Fanfarillo et al. 2020c), and are also present in other environments, particularly in semi-natural herbaceous vegetation.

This means they are not exclusive to segetal habitats. Furthermore, these species are part of annual plant communities that are common in the Mediterranean basin due to dry summers, which promote annual plants. However, this competition sometimes leads to a lower robustness of species outside or at the limits of their range and for this reason, strictly segetal species that are disappearing in northern European countries, such as the archaeophytes *Ajuga chamaepitys* (L.) Schreb., *Filago pyramidata* L. and *Lathyrus aphaca* L. remain widespread in Italy, extending beyond purely segetal habitats. Compared to past inventories based on Italian winter arable crops (e.g., winter cereal and legume), olive groves, and vineyards (see Fanfarillo et al. 2019, 2020a, b, c) this effort shows an important increase in the number of segetal species listed. This study further reveals that the species identified in Sardinian fields largely overlap with the most prevalent weed flora commonly observed in artichoke fields across the Mediterranean region (Al Mohandes et al. 2012; Fracchiolla et al. 2022).

In the absence of weed control practices, the common segetal species emerging in fields after planting globe artichoke are predominantly summer species, which often appear following irrigation. This phenomenon may be attributed to the tropical or sub-cosmopolitan origins of these taxa, where some of them also have a C4 assimilation pathway, as their growth is favored by high temperatures and with higher water-use efficiency (Brullo and Guarino 2007). They are, for example, *Amaranthus* sp. pl., *Digitaria sanguinalis*, *Echinochloa* sp. pl., *Setaria* sp.pl., and *Portulaca oleracea*. However, due to irrigation, some species with C3 metabolism can be favored as well, for example *Chenopodium album*, *Convolvulus arvensis*, *Datura stramonium*, *Euphorbia* sp. pl., *Polygonum aviculare*, *Solanum nigrum*, *Xanthium strumarium*. It is worth noting that *C. arvensis* and *Mercurialis annua* tend to be present throughout all seasons, while *Lamium purpureum* is more commonly associated with late winter to spring. The following species have an autumn-winter emergency: *Anthemis arvensis* and *Oxalis pes-caprae*.

In addition, the high number of therophytes in the segetal flora of artichoke fields in Sardinia can be attributed to their adaptive growth in disturbed agroecosystems with seasonally dry climates. This prevalence is also reflected in the chorological spectrum, which shows a high proportion of Mediterranean and widely distributed (cosmopolitan or sub-cosmopolitan) taxa, indicating that these species are well adapted to both anthropogenic disturbances and the climatic constraints typical of Mediterranean agroecosystems (Guarino and Mossa 2006).

Despite the number of native species found in artichoke fields, also neophytes were commonly found, such as *Amaranthus blitoides*, and *Oxalis pes-caprae*, which are classified as naturalized and invasive and common also in the types of irrigated fields (Cossu et al. 2014; Tiloca et al. 2024). Notably, *O. pes-caprae* ranks among the most challenging invasive species in Mediterranean islands, commonly found in disturbed and ruderal habitats, as well as extensively present in agroecosystems (Petsikos et al. 2007). Its presence has led to a marked reduction in native plant diversity (around 10%) with annual species being particularly affected (Vilà et al. 2006). The occurrence of *O. pes-caprae* in conventional systems is likely promoted by elevated soil nutrient levels, which invasive species exploit more efficiently (Sala et al. 2007). Furthermore, increased water availability due to irrigation exacerbates the vulnerability of these systems to colonization (Juárez-Escario et al. 2017; Mojzes et al. 2020).

It is well known that archaeophytes were associated in ancient times with traditional crops such as cereals and that their presence declined in fields dominated by more recent crops such as maize and rapeseed, where neophytes were more prevalent. Furthermore, archaeophytes were introduced during early agricultural development in the Neolithic, while neophytes have become increasingly common with modern agricultural intensification Colling et al. (2025).

In this context, neophytes can significantly reduce native species' richness or replace them and alter the floristic composition of segetal plant communities. Colling et al. (2025) examined the spread of non-cultivated alien plant species in crop fields across ten Central European countries. They found that the proportion of plots in which neophytes were present increased from 34.2% (1930) to 70.1% (2019). In addition, the study highlighted that neophytes spread is driven primarily by a few common species, such as *Veronica persica* (present in our study) and *Erigeron annuus*, which had a high number of records during the study period. These findings suggest that neophytes, particularly those with high dispersal capacity and competitive advantages, can displace native species, leading to a homogenization of plant communities and a decrease in biodiversity. This is a consequence of modern agricultural practices (i.e., soil disturbance and fertilizer use) that promote the growth and competitiveness of neophytes. Due to the increase in stronger neophytes, the relative abundance of archaeophytes may have declined. This is also reflected in our study area, where only one of the 113 species found was an archaeophyte.

Like almost all plant species checklists, the one presented here reflects the data available at a given time (in this case, up to 2021). While it provides a valuable overview, ongoing findings, especially of neophytes, mean that such inventories evolve naturally. To ensure they reflect the most current knowledge, species lists should be updated regularly, ideally through continuously maintained databases. In conclusion, this study provides the first inventory on the segetal flora of artichoke fields on the island of Sardinia. The information in this paper revealed a notable species diversity of the flora of artichokes and has outlined its main characteristics, which may be summarized as the remarkably high native species within the agroecosystems, and a rich flora, mainly composed of native species well adapted to human disturbance, along with a variety of taxa of neophytes. The inventory and its upcoming updates will serve as a valuable resource for new research focused on this important yet often overlooked aspect of biodiversity in human-altered environments.

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Supplementary material 1

List of the segetal flora in *Cynara cardunculus* L. (globe artichoke) cropping system in Sardinia

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Data type: docx

Explanation note: List of the segetal flora in *Cynara cardunculus* L. (globe artichoke) cropping system in Sardinia with families, life forms (Ch = chamaephytes, H = hemicryptophytes, G = geophytes and Th = therophytes), chorotypes, biogeographic status (Arch = archaeophyte; Nat = native; Neo = neophyte; Cryp = cryptogenic) and invasive status in Sardinia (NAT = naturalized, INV = invasive). Families are ordered phylogenetically according to the linear classification of flowering plants (APG IV) and species are ordered alphabetically within each family. .

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