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Research Article

Alien species of *Ipomoea* in Greece, Türkiye and Iran: distribution, impacts and management

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Abstract

New introductions of alien *Ipomoea* species and their negative impacts have increased in Greece, Türkiye, and Iran. However, little is known about their current status, distribution, impacts, and management. Here, we provide a detailed overview of *Ipomoea* species in these countries and discuss the current and proposed management options for restoring invaded plant communities. We report on four alien *Ipomoea* species in Greece (three naturalized and one casual), 10 in Türkiye (eight naturalized and two casual), and 11 in Iran (eight naturalized of which two are invasive and three casual). Their most significant negative impact was detected in agricultural areas, especially in spring crops like soybean, cotton, and maize, with *I. hederacea*, *I. purpurea*, and *I. triloba* being the most troublesome weeds. Native plants are mainly threatened by *I. indica*, *I. leucantha*, and *I. triloba*. The management of *Ipomoea* species differs according to the habitats invaded; in agricultural areas, the management is more dependent on the host crop and the available registered herbicides, whereas in areas with natural habitats, other management options such as mechanical and biological measures are more appropriate. The information from this work will be useful for the early detection of *Ipomoea* species in countries neighboring the already invaded ones.

Key words: Biological invasion, casual plant, herbicides, management, naturalized plant

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Introduction

Invasive alien species (IAS) are considered one of the greatest threats to native ecosystems and biodiversity (Pyšek et al. 2020a; IPBES 2023) and have received increasing attention from scientists and policy-makers in recent decades due to their detrimental ecological impact (Hejda et al. 2009; Pyšek et al. 2012; Blackburn et al. 2014; Kumschick et al. 2015; Rumlerová et al. 2016) and economic cost (Novoa et al. 2021; Diagne et al. 2022; Tarkan et al. 2024). Plants are the most represented group of alien organisms and, similar to other groups, their numbers in invaded regions are increasing globally, as are the rates of new introductions (van Kleunen et al. 2015; Pyšek et al. 2017; Seebens et al. 2017, 2019).

The taxonomic distribution of plant families and genera in the global naturalized flora is highly heterogeneous, with at least one naturalized species present in 287 families and 2984 genera (van Kleunen et al. 2019). One of the genera with the highest representation of naturalized aliens worldwide is *Ipomoea* from the family Convolvulaceae (Pyšek et al. 2017). The etymology of the name *Ipomoea* comes from the Greek words *"ips"* meaning "worm" and *"homoios"* meaning "similar to", reflecting the wormlike twining habit of the genus (Rojas-Sandoval and Acevedo-Rodríguez 2014). Pyšek et al. (2017), in their overview of global naturalized flora, reported 55 *Ipomoea* species (i.e., 11.8% of all taxa in the genus) and 1348 region × species records; they considered 47 taxa as naturalized on mainland worldwide and 42 on islands.

This global picture of the invasion by *Ipomoea* taxa can be enhanced by using regional data from different parts of the world. For example, in Congo, there are 11 alien/naturalized *Ipomoea* species among 20 members of Convolvulaceae (Bordbar and Meerts 2022); in Oman, the corresponding proportion was four out of five (Patzelt et al. 2022); in Pakistan, nine out of 14 species (Jehangir et al. 2024) and in India, 12 *Ipomoea* species were reported among the 19 Convolvulaceae species (Inderjit et al. 2018). Approximately 20–25 very widespread naturalized and invasive *Ipomoea* species have been reported in almost all tropical countries, in both the Old and New World (Wood and Scotland 2017; Wood et al. 2020). However, *Ipomoea* species have been widely introduced for ornamental purposes (GBIF 2024; Royal Botanic Gardens Kew 2024) or unintentionally through contaminated seeds of crops such as soybean, cotton, or oilseeds (CABI 2024). They have been reported as invasive in many countries, such as Japan (Mito and Uesugi 2004), India (Chandra 2012), China (Liu et al. 2016; Hao and Ma 2022), Hawaii (PIER [Pacific Islands Ecosystems at Risk] 2017), and South Africa (Pyšek et al. 2020b). Taking into account their widespread introductions and strong invasion potential, more information on their taxonomy and geographical distribution is essential for selecting appropriate management options. This knowledge will help to prioritize the species that are problematic in a particular area and establish management programs accordingly (Pyšek et al. 2020a, b). Thus, preventive measures can be taken, which is one of the first priorities for the management of potential invasive taxa that may cause problems in an area. In addition, gaps in their management can be identified in advance and thus management programs can be developed against possible risks (Pyšek et al. 2020a; García-Díaz et al. 2022).

Ipomoea taxa are annual or perennial climbing herbs, shrubs or even small trees; the genus comprises approximately 600 taxa (Mabberley 2017). Some perennial taxa have tubers on their roots and exhibit strong phenological patterns, such as dormancy during cold and dry winters (Muñoz Rodríguez et al. 2019; Wood et al. 2020). Species of the genus *Ipomoea* have a C3 photosynthetic pathway and are thus likely to benefit from the rising atmospheric CO_2 due to climate change (Velumani et al. 2017). For instance, it has been reported that a higher frequency of heat disturbance under global warming will increase the invasiveness of *I. cairica* while suppressing the growth of the native vine *Paederia scandens* in southern China (Chen et al. 2023). The negative impacts of *Ipomoea* taxa are related to the mechanisms that make them strong competitors, such as phototropism, circumnutating, and shade avoidance responses (Price and Wilcut 2007; Paul and Yavitt 2011; Pagnoncelli et al. 2017; Pazzini et al. 2022; Asami et al. 2023), as well as having a fast growth rate and rapid and easy dispersal by seeds and stem fragments (Norsworthy and Oliver 2002; Kati and Giannopolitis 2006; Moura and Morim 2015; Giraldeli et al. 2019; Helman et al. 2020; Onen et al. 2023). In addition, some species are allelopathic or may host plant pathogens (Shen et al. 2019; Cabral et al. 2023), increasing their negative impact on the local indigenous flora of invaded areas.

Greece, Türkiye and Iran, which form a longitudinal gradient stretching from from 21° W, have suitable biological and ecological characteristics for the establishment of *Ipomoea* species, leading to a rapid increase in the number of reported new records of these taxa. *Ipomoea* species invade a wide range of habitats across both natural and agricultural lands. For instance, soybean fields in USA, Iran and Japan (Howe and Oliver 1987; Sohrabi et al. 2017; Asami et al. 2023), cotton and corn fields in Greece and Türkiye (Giannopolitis and Papachristos 1997; Yazlık et al. 2018), coastal areas in China (Liu et al. 2016) and temperate rainforest in Australia (Bernich et al. 2024) have been severely affected by these species.

Appropriate management of invasive or potentially invasive alien plants depends on detailed information on their pathways of introduction, status, impacts, and distribution (Pyšek et al. 2004; Pergl et al. 2017; Ricciardi et al. 2017; Potgieter et al. 2022). Concerted management actions are needed to prevent their further spread and to minimize the harmful impacts, especially in countries with a wide range of natural habitats and rich native floras (Arianoutsou et al. 2010; Uludağ et al. 2017). The aim of the current paper is to provide a detailed overview of *Ipomoea* species in the affected countries, including current distribution status, and detected impacts. We also provide an overview of management options, current and proposed, to restore *Ipomoea*-invaded plant communities.

Materials and methods

Study area

Greece is a southeastern European country occupying the southern part of the Balkan Peninsula, with a latitude of 39.0742°N and a longitude of 21.8243°E. It has land borders with Albania, North Macedonia, Bulgaria to the north, and Türkiye to the east, and is surrounded by the Aegean Sea (east), the Cretan and the Libyan Seas (south), and the Ionian Sea (west). It has a total area of 131,957 km^2, of which about 83% is mainland. It has a coastline of 13,676 km, the longest in Europe, and about 6000 islands, of which 227 are inhabited. Almost 80% of Greece is mountainous, with Mount Olimbos (Olympus) being the highest mountain (2,918 m a.s.l.). The Macedonian (northern) and Thessalian (central) plains are the largest in the country and are mainly used for agriculture, horticulture, and forestry. The climate of Greece is predominantly Mediterranean, with mild and rainy winters, warm and dry summers and, generally, long periods of sunshine throughout most of the year. Greece has one of the richest vascular floras in Europe, with 5,959 species and 2,013 subspecies (native and naturalized), representing 6,846 taxa (Dimopoulos et al. 2023).

Türkiye is a large peninsular country between 36°42' north latitude and 26°45' east longitude, with a total land area of 783,562 km^2. The southern border is defined by the island of Cyprus and the Mediterranean Sea, the western border by the Aegean Sea, and the northern border by the Black Sea. Most of its land mass is in Anatolia, with a small part in Thrace, the south-eastern extension of the Balkan Peninsula. Geographically, Türkiye lies on the border between Europe and Asia. The Sea of Marmara and the Straits of Istanbul and Çanakkale separate Anatolia from

Thrace, effectively dividing Asia from Europe. Due to Türkiye's location as a transition point between Asia and Europe and the three distinct phytogeographic regions it encompasses (Mediterranean, Iran-Turanian, European-Siberian), the country has a rich flora, with more than 12,000 plant taxa. The majority are native taxa, and 31% of the native taxa are endemic (Güner et al. 2000; Uludağ et al. 2017).

Iran, with an area of 1,648,195 km^2, is located in the arid belt of the eastern hemisphere, in western Asia, between the northern latitudes of 25–45° and the eastern longitudes of 44–63°. It is bordered to the north by the Caspian Sea and to the south by the Persian Gulf and the Sea of Oman. Two high mountain ranges, the Alborz in the north and the Zagros in the west, play a vital role in preventing the Mediterranean and the Caspian Sea winds near the central plateau in Iran. The vascular flora of Iran consists of nearly 8,660 species, of which 2,760 are endemic (Mozaffarian 2024).

Data collection

We used local and regional journals and book chapters, supplemented by Google searches to locate grey literature publications, such as country reports and proceedings articles not included in the scholarly databases. The search included literature related to alien *Ipomoea*, using the following terms: "*Ipomoea* species" or "alien *Ipomoea*" or "new records of *Ipomoea* species" plus country name (Greece, Türkiye and Iran). Our final list comprised 35 documents, including 10 journal articles, two technical reports, and three other documents for Iran; 16 journal articles and three grey citations (three master theses – Arslan 2022; Doğru 2023; Saruhan 2024) for Türkiye; nine journal articles and two online databases for Greece. Information on *Ipomoea* species and their current status, actual impact, and management in all three countries was searched using combinations of keywords such as: "*Ipomoea* species invasion", "invader", "alien species", "exotic species", "*Ipomoea* management/control", "weed management in maize/cotton/soybean" and "country name" either as topic or title from local studies and literature review. In addition, some information was obtained from field observations made during plant growth (end of May to October for Iran, May to November in Türkiye) during 2019–2024. Other data on general aspects of the studied species were obtained through Google searches from different databases and research articles.

The stage that the alien *Ipomoea* species under study reached in the naturalization/invasion process (Richardson et al. 2000) was identified for each country: (i) casual alien, (ii) naturalized species (synonym: established species), and (iii) invasive species (Richardson et al. 2000; Blackburn et al. 2011). We also assigned each species to the most commonly invaded habitat types (Suppl. material 1) in the three countries, using the classification of the SynHab project (www.synhab.com; Hejda et al. 2015; Pyšek et al. 2022; Dawson et al. 2025). The following habitat types were distinguished to classify species' habitat preferences: 1. Forest, 2. Open forest, 3. Scrub, 4. Grassland (divided into 4a. Natural grassland, 4b. Human-maintained grassland), 5. Sandy, 6. Rocky, 7. Dryland, 8. Saline, 9. Riparian, 10. Wetland, 11. Aquatic, 12. Artificial (divided into 12a. Ruderal/urban habitats, 12b. Agricultural habitats).

We used the WGS84 geographic coordinate system with an EPSG code of 4326 to map the distribution of the 14 identified species. The map was created at a scale 1:10,000,000 and utilized the image was generated using QGIS and Esri World Data 2021. Geographical coordinates of the detected species were taken from GPS and regional databases (Flora Hellenica database, personal communication with Arne Strid).

Distribution of *Ipomoea* taxa in Greece, Türkiye and Iran

Ipomoea taxa in Greece

Four alien species of *Ipomoea* have been recorded in Greece: *Ipomoea purpurea*, *I. hederacea*, and *I. indica* are naturalized, and *I. batatas* is casual (Fig. 1, Table 1). *Ipomoea purpurea*, which was introduced as an ornamental and has escaped and successfully established in various ecosystems, is the most widespread (Strid 2024). *Ipomoea hederacea*, locally known as 'agriofasoulia' (wild bean), is the most recently introduced species of *Ipomoea* in Greece, first reported in the early 1990s in the Preveza Prefecture (western Greece). It was probably introduced as a seed contaminant and caused major problems in irrigated summer crops, particularly in maize and cotton (Giannopolitis and Papachristos 1997; Drolia 2004; Giannopolitis et al. 2004; Kati and Giannopolitis 2004, 2006; Anagnou-Veroniki et al. 2008). Later studies reported that this weed has spread to several other cultivated areas in western Greece and in Thessaly (central Greece), infesting cotton-growing areas of in the Prefecture of Karditsa (Kati and Giannopolitis 2017). *Ipomoea batatas* was cultivated in the country before 1962; its introduction probably occurred earlier as in the case of many other crops (Valíček et al. 2002; Hobhouse et al. 2004; www.fao.org/faostat). It sometimes reproduces in the wild through underground propagules.

Table 1. The *Ipomoea* species in Greece, Türkiye and Iran, their invasion characteristics and introduction pathways.

	Species	Invasion status	Year of introduction	*Habitat type codes	Introduction pathway
	Ipomoea batatas (L.) Lam.	Casual	>1962	12b	Release
Greece	*Ipomoea hederacea* Jacq.	Naturalized	1994	12a, 12b	Contaminant
	Ipomoea indica (Burm.) Merr.	Naturalized	1972	12a, 12b	Release
	Ipomoea purpurea (L.) Roth	Naturalized	1986	12a, 12b	Contaminant
Türkiye	*Ipomoea batatas* (L.) Lam.	Casual	1900	12a, 12b	Release
	Ipomoea coccinea L.	Naturalized	2016	12a, 12b	Escape
	Ipomoea hederacea Jacq.	Naturalized	1999	12a, 12b	Escape / Contaminant
	Ipomoea hederifolia L.	Naturalized	2016	12b	Escape / Contaminant
	Ipomoea indica (Burm.) Merr.	Naturalized	2018	12a	Escape / Release
	Ipomoea lobata (Cerv.) Thell.	Casual	2023	12a	Cultivated in a Botanical Garden
	Ipomoea nil (L.) Roth	Naturalized	Unknown	Data Deficient	Data Deficient
	Ipomoea purpurea (L.) Roth	Naturalized	1918	12a, 12b	Escape / Contaminant
	Ipomoea tricolor Cav.	Naturalized	2016	12a, 12b	Escape / Contaminant
	Ipomoea triloba L.	Naturalized	2000	4a, 9, 12a, 12b	Contaminant
Iran	*Ipomoea batatas* (L.) Lam.	Casual	1970–1980	12a, 12b	Release
	Ipomoea cairica (L.) Sweet	Naturalized	2002	12b	Release
	Ipomoea carnea s.l.	Naturalized	2002	12b	Escape
	Ipomoea coccinea L.	Casual	2020	12b	Release
	Ipomoea hederacea Anon.	Invasive	2010	12a, 12b	Contaminant
	Ipomoea indica (Burm.) Merr.	Invasive	2019	2, 12b	Escape/ Release
	Ipomoea lacunosa L.	Naturalized	2018	12a, 12b	Contaminant
	Ipomoea leucantha Jacq.	Naturalized	2010	2, 12a, 12b	Contaminant
	Ipomoea purpurea (L.) Roth	Naturalized	1949	12a, 12b	Escape
	Ipomoea tricolor Cav.	Casual	2010	12b	Release
	Ipomoea triloba L.	Naturalized	2008	12b	Contaminant

*Habitat_type_description (SynHab: www.synhab.com): 1 Forests, 2 Open forests, 3 Scrub, 4 Grasslands (4a Natural grassland, 4b Human maintained grasslands), 5 Sandy, 6, Rocky, 7 Dryland, 8 Saline, 9 Riparian, 10 Wetland, 11 Aquatic, 12 Human-made (12a Ruderal_habitats, 12b Agricultural_habitats).

Figure 1. The distribution of 14 alien *Ipomoea* taxa in Greece, Türkiye and Iran.

Ipomoea taxa in Türkiye

In the last two decades, alien *Ipomoea* taxa have been introduced to Türkiye both intentionally and unintentionally (Gönen 1999; Yazlık et al. 2014; Uludağ et al. 2017; Hançerli et al. 2018; Yazlık et al. 2018; Özkil and Üremiş 2020; Onen et al. 2023; TÜİK 2023). The genus comprises 10 alien taxa; all of which are naturalized except for *I. batatas* and *I. lobata* which are casual (Fig. 1, Table 1).

Ipomoea coccinea has been observed in disturbed areas along roads, on the edges of tea plantations, in abandoned fields, and in other wastelands (Onen et al. 2021). *Ipomoea hederacea* was first recorded in Türkiye as a weed by Gönen (1999) and has recently been recognized as a problematic plant together with *I. purpurea and I. triloba* in many agricultural areas: in cotton, peanut, soybean and maize fields, pomegranate and citrus (orange, tangerine) orchards and eggplant production areas (Özkil and Üremiş 2020). *Ipomoea triloba* was first recorded by Yazlık et al. (2014). This species has serious environmental and socio-economic impacts in agricultural areas, coastal areas, pastures (except arable land), stream margins, and man-made habitats (Yazlık et al. 2018). In recent years, the distribution area and population size of this species have continued to increase in the Mediterranean, Aegean, and southeastern Anatolia regions of Türkiye (Yazlık et al. 2018; Özkil et al. 2019; Özkil and Üremiş 2020; Arslan and Kitiş 2021; Doğru and Kitiş 2023). *Ipomoea hederifolia* was first recorded by Hançerli et al. (2018) and detected in maize fields in Adana province in the eastern Mediterranean part of Türkiye in 2016. *Ipomoea tricolor* has long been cultivated as an ornamental plant in gardens and some landscape areas in Türkiye (Yücel 2002; Uludağ et al. 2017), and it is found in agricultural and ruderal habitats (Onen et al. 2023).

Ipomoea purpurea was first cultivated in 1918 and is often grown in gardens, and sometimes escaping into the wild. Due to its use as an ornamental plant, it has spread rapidly in many regions in Türkiye, especially along the Mediterranean and Aegean coasts. (Hançerli et al. 2018; Özkil and Üremiş 2020). An alien record of *I. nil* in Türkiye was reported by Uludağ et al. (2017), who consider the species to be naturalized there and there is evidence that its seeds are sold as an ornamental plant in the Marmara region of Türkiye. Similarly, *I. indica* and *I. lobata* are also used for ornamental purposes in the Mediterranean region (Ercan et al. 2018; Öztürk and Görhan 2021; Esener 2023, Fig. 1, Table 1). The casual alien species *I. batatas* has been cultivated as a crop in Türkiye (Çalışkan et al. 2007; Özelçam 2013). Currently, the areas where it is grown are quite limited, reaching 35 ha in eight provinces (TÜİK 2023). No case of *I. batatas* escaping into the wild and becoming a problem has been reported.

Ipomoea taxa in Iran

There are 11 alien *Ipomoea* species in Iran, of which three are casual and eight naturalized. Two of the naturalized species are invasive (Fig. 1, Table 1): *Ipomoea indica* and *I. hederacea*. The former is considered invasive as an environmental weed in open forests and natural landscapes, while the latter is more common in agricultural areas, especially in cotton, soybean, and maize production areas in northern Iran (Pahlevani and Sajedi 2011; Sohrabi and Gherekhloo 2015; Sohrabi et al. 2017; Amini et al. 2020). Most *Ipomoea* species are restricted to northern and southern Iran (Fig. 1, Table 1), where winter temperatures are above zero.

Three species have recently been recorded in northern Iran, probably introduced with cotton seed (*I. lacunosa* and *I. leucantha*) or for ornamental purposes (*I. coccinea*) (field observation by SS and JG). *Ipomoea cairica*, *I. carnea*, and *I. triloba* have been recorded in southern Iran and are restricted to ruderal habitats (Pahlevani and Sajedi 2011; Sohrabi et al. 2023a, b). *Ipomoea tricolor* and *I. purpurea* are used as ornamentals in some parts of the country (Farahmand 2018), while *I. purpurea* has been detected as a weedy species in soybean production in the Golestan and Mazandaran provinces (Savari-Nejad et al. 2010; Abbasi et al. 2022). Although *I. batatas* has an older history in the country than other species, it has not been cultivated to its full potential (Koocheki et al. 2018).

Comparison of the distribution of 14 alien *Ipomoea* in our study area revealed that the widespread species differed among the three countries. *Ipomoea purpurea* and *I. indica* were more common in Greece, while *I. batatas* and *I. triloba* were more common in Türkiye. *Ipomoea purpurea* and *I. batatas* also had a wider distribution in Iran than other species (Fig. 1). A higher number of occurrences in Greece compared to Türkiye and Iran may be attributed to the combination of a more widespread distribution and more intensive sampling in this region. Further monitoring will be essential for tracing the geographical patterns of *Ipomoea* species. Understanding alien plant species' geographical distribution and dispersal ability is important for land managers and policymakers to apply optimal management strategies (Zhou et al. 2021).

Impacts of alien *Ipomoea* taxa

In Greece, the impact of alien *Ipomoea* species mainly concerns *I. hederacea* and *I. indica*. *Ipomoea hederacea* is a troublesome weed of cotton, maize, and other spring crops (Table 2). Most problems occur in western and central Greece (Giannopolitis et al. 2004; Kati and Giannopolitis 2017). It climbs on plants and causes problems in cultivation practices, especially at harvest (Drolia 2004; Giannopolitis et al. 2004). It is characterized by a high phenotypic plasticity, with its main stem reaching up to 3 m in length when growing between tall crops such as maize. In cotton, it produces long lateral shoots, with the main stem reaching up to the height of the crop. The climbing nature of *I. hederacea*, its circular movement and its ability to adapt its growth pattern according to the structure and size of the crop canopy, results in a dense network of wiry shoots surrounding the crop plants, making harvesting difficult or, in the case of dense weed infestations, impossible. It is also a strong competitor that grows rapidly, and is dispersed mainly by seed, although it can also re-sprout from stem cuttings (Kati and Giannopolitis 2006). *Ipomoea hederacea* seeds can germinate after shedding without the need for post-ripening (Kati and Giannopolitis 2006). Their germination is initiated when soil moisture is adequate, usually triggered by spring rains or irrigation of summer crops. This has resulted in dense populations of *I. hederacea* along irrigation canals, where they have outcompeted local indigenous species and served as a seed source, contaminating neighboring crops.

Reports on *I. indica* are more localized, and mainly refer to the presence of this species on the island of Rodos (Rhodes) (Dodecanese, eastern Greece). *Ipomoea indica* from the Kremasti and Mandriko areas of Rodos was found to be the host of the SPLCV virus which belongs to the sweepoviruses (Fiallo-Olivé et al. 2014). This virus can potentially infect native plants of the Convolvulaceae family, such as *I. sagittata* and *I. imperati* (Strid 2024). Galanos (2015) highlighted the presence of *I. indica* as a cause of native biodiversity loss on the island of Rodos.

In Türkiye, the most important impacts of *Ipomoea* are related to *I. hederacea*, *I. purpurea* and *I. triloba*, which cause problems in cotton and maize fields (Table 2, Fig. 2) in the Aegean, Mediterranean and Southeast Anatolian Regions (Muslu and Tepe 2016; Yazlık et al. 2018; Özkil et al. 2019; Özkil and Üremiş 2020; Arslan and Kitiş 2021; Doğru and Kitiş 2023). The climbing habit of these taxa gives them a competitive advantage over cotton and even reduces the amount of product by preventing the opening of cotton capsules (Yazlık et al. 2018; Özkil and Üremiş 2020; Arslan and Kitiş 2021). In addition, *I. triloba* causes serious problems by blocking irrigation canals in the Mediterranean region (Yazlık et al. 2018). On the other hand, *I. purpurea* and *I. hederacea* are used as ornamental plants in many regions of Türkiye. Cultivation creates a strong propagule pressure which allows the species to escape to different habitats (Table 1).

The population size of *I. hederifolia* is rapidly increasing in the Çukurova plain, one of the largest plains in Türkiye, where polyculture agriculture is practiced in the Mediterranean province of Adana. This has caused remarkable yield losses and harvest problems in maize fields (Hançerli et al. 2018).

Among other species, *I. coccinea* has a major socio-economic impact on tea plantations (Onen et al. 2021), which is the main product of the eastern Black Sea region of Türkiye and is cultivated over large areas (TÜİK 2023). Given the strong competitive ability of *I. coccinea*, supported by its high seed production and ivy-like structure, its rapid spread into different habitats and increase in population density and distribution in this region is likely. Similarly, *I. tricolor* is another species whose potential distribution in the Black Sea, Aegean, Mediterranean and some parts of central Anatolia has been predicted to increase according to a model based on germination and other traits (Onen et al. 2023).

Table 2. The detected mechanisms of impact of *Ipomoea* species in Greece, Türkiye and Iran and affected crop/native taxa.

	Species	*EICAT Criteria impact mechanism(s)	Affected crops/ native taxa	References
Greece	*Ipomoea batatas* (L.) Lam.	DD	Unknown	www.europlusmed.org
	Ipomoea hederacea Jacq.	1	Cotton, corn, Lucerne	Hobhouse et al. 2004; Kati and Giannopolitis 2006
	Ipomoea indica	1, 4, 11	Environmental weed	Fiallo-Olivé et al. 2014; Galanos 2015
	Ipomoea purpurea (L.) Roth	1	Agricultural and ruderal habitats	Arianoutsou et al. 2010; Baliousis 2014
Türkiye	*Ipomoea batatas* (L.) Lam.	8, 12	Cultivated	Çalışkan et al. 2007; Özelçam 2013; TUİK [Turkish Statistical Institute] 2023
	Ipomoea coccinea L.	1, 11, 12	Tea plantations	Ercan et al. 2018; Onen et al. 2021; Öztürk and Görhan 2021
	Ipomoea hederacea Jacq.	1, 11	Cotton, soybean, tobacco, peanuts, potatoes, sugar beets, sunflowers, corn, orchards (citrus fruits, apples, plums, apricots, almonds, olives, dates, pomegranates, cherries, walnuts, pears, peaches, bananas, loquats), strawberries and vineyard fields	Gönen 1999; Özkil and Üremiş 2019, 2020
	Ipomoea hederifolia L.	1, 11	Corn	Hançerli et al. 2018
	Ipomoea indica (Burm.) Merr.	1, 11, 12	Gardens	Ercan et al. 2018; Öztürk and Görhan 2021
	Ipomoea lobata (Cerv.) Thell.	DD	Cultivated in a botanical garden	Esener 2023
	Ipomoea nil (L.) Roth	DD	Gardens	Uludağ et al. 2017
	Ipomoea purpurea (L.) Roth	1, 11, 12	Cotton, soybean, tobacco, peanuts, potatoes, sugar beets, sunflowers, corn, orchards (citrus fruits, apples, plums, apricots, almonds, olives, dates, pomegranates, cherries, walnuts, pears, peaches, bananas, loquats), strawberries and vineyard fields	Davis et al. 1988; Aykurt 2012; Muslu and Tepe 2016; Ercan et al. 2018; Özkil and Üremiş 2020; Öztürk and Görhan 2021
	Ipomoea tricolor Cav.	1, 11, 9	Gardens, edge of agricultural fields	Yücel 2002; Onen et al. 2023
	Ipomoea triloba L.	1, 9, 11, 12	Cotton, soybean, tobacco, peanuts, potatoes, sugar beets, sunflowers, corn, orchards (citrus fruits, apples, plums, apricots, almonds, olives, dates, pomegranates, cherries, walnuts, pears, peaches, bananas, loquats), strawberries and vineyard fields	Yazlık et al. 2018; Özkil et al. 2019; Özkil and Üremiş 2020; Arslan and Kitiş 2021; Doğru and Kitiş 2023
Iran	*Ipomoea batatas* (L.) Lam.	DD	Unknown	Koocheki et al. 2018
	Ipomoea cairica (L.) Sweet	DD	Unknown	Farahmand 2018
	Ipomoea carnea s.l.	DD	Unknown	Farahmand 2018
	Ipomoea coccinea L.	1, 11	*Mercurialis* sp.	Fields observation 2022, 2023
	Ipomoea hederacea Anon.	1	Cotton, corn and soybean	Pahlevani and Sajedi 2011;
	Ipomoea indica (Burm.) Merr.	1, 11	*Gleditsia caspica* Desf.	Amini et al. 2020; Sohrabi et al. 2023c
	Ipomoea lacunosa L.	1, 11	*Urtica dioica*, *Ficus carica*	Fields observation 2022, 2023
	Ipomoea leucantha Jacq.	1, 11	Cotton and soybean, *Punica granatum*	Fields observation 2022, 2023
	Ipomoea purpurea (L.) Roth	1, 6	Cotton, corn, soybean and ornamental plants	Savari-Nejad et al. 2010; Farahmand 2018; Rashidi et al. 2020
	Ipomoea tricolor Cav.	6	Ornamental plants	Gholamalipour Alamdari et al. 2019
	Ipomoea triloba L.	1	Fields and orchards	Pahlevani and Sajedi 2011

*EICAT Criteria impact mechanisms: (1) Competition, (2) Predation, (3) Hybridisation, (4) Transmission of diseases to native species, (5) Parasitism, (6) Poisoning/ toxicity, (7) Bio-fouling, (8) Grazing/herbivory/browsing, (9) Chemical impact on ecosystem, (10) Physical impact on ecosystem, (11) Structural impact on ecosystem, (12) Indirect impacts through interactions with other species (Kumschick et al. 2024). DD = data deficient.

Recently, the first analysis of the economic costs of alien species in Türkiye from 1960 to 2022 reported a total of 4.1 billion USD, the largest share of which (2.85 billion USD) was due to the agricultural sector (Tarkan et al. 2024). Considering this situation, early identification of problems caused by alien species and rapid establishment of appropriate management measures, including precautionary measures against the relevant species, would prevent future high invasion impacts (Pyšek et al. 2020a; García-Díaz et al. 2022). Therefore, the serious impacts of many of the *Ipomoea* taxa reported here in agricultural habitats (Table 1) should be taken into consideration.

In Iran, *I. hederacea*, *I. indica*, *I. purpurea*, and *I. leucantha* are the most important alien species of the genus in terms of negative impacts. *Ipomoea hederacea* and *I. purpurea* are important weeds causing yield losses in summer crops such as soybean and cotton (Pahlevani and Sajedi 2011; Abbasi et al. 2022). *Ipomoea hederacea* has been included in a list of plant quarantine pests in Iran (Anonymous 2015),

Figure 2. *Ipomoea triloba* L. in maize and citrus cultivation in Turkiye. ©Yasin Emre Kitiş.

and our survey revealed its new distribution in cotton production areas in Ardebil province. *Ipomoea indica* threatens native plants such as *Gleditsia caspica* and native grasses in the Mazandaran province (Amini et al. 2020). The field observations showed that the presence of *I. leucantha* and *I. lacunosa* reduced the growth of native plants such as *Urtica dioica*, *Mercurialis* sp., *Ficus carica* and *Punica granatum* (Table 2, Fig. 3). We observed *I. leucantha* as a new serious weed in cotton producing areas in the Kordkuy township (Fig. 4). *Ipomoea hederacea* is a troublesome weed in summer crops in Golestan (Pahlevani and Sajedi 2011; Siahmarguee et al. 2022).

The potential negative impact of the casual species of the genus in Iran (*I. tricolor*, *I. coccinea*, and *I. batatas*) needs further investigation. The allelopathic effect of *I. tricolor* is due to secondary compounds such as phenols and anthocyanins, which have been suggested as main inhibitory compounds (Gholamalipour Alamdari et al. 2019).

Impacts of *Ipomoea* species elsewhere

Many reports have highlighted the detrimental impacts of *Ipomoea* species, such as *I. purpurea*, referring to competition, allelopathy, and serving as alternative hosts for plant viruses (Crowley and Buchanan 1978; Zhang et al. 2014; Cabral et al. 2023). Negative impacts have been reported for *I. cairica* and *I. carnea*, which are globally distributed (Damir et al. 1987; Milne and Walter 2000; Liao et al. 2006; Zhao and Peng 2008; Ma et al. 2009; Takao et al. 2011; Zhu and Wu 2012; Sadek 2014). The invasion success of *I. carnea* in Egypt has been attributed to allelopathy coupled with competition for soil nutrients (Sadek 2014). *Ipomoea cairica* is recognized as the second worst invasive weed in southern China due to its extremely rapid growth, sprawling habit, and perennial life history (Wu and Hu 2004), and is predicted to become even more invasive with global warming (Wang et al. 2011). *Ipomoea batatas* is also allelopathic, but more information is needed on its potential toxicity to fauna and flora in invaded areas (Zhang et al. 2014). Hybridization, competition, and

Figure 3. *Ipomoea leucantha* Jacq., *I. lacunosa* L. and *I. indica* (Burm.) Merr. in different locations from left to right, respectively, in Golestan (1 and 2), and Mazandaran (3) Iran. ©Javid Gherekhloo.

Figure 4. The growth of *Ipomoea leucantha* Jacq.and *I. hederacea* Anon. on cotton and soybean plant to reach light and shading out crop in the north of Iran. ©Javid Gherekhloo.

disease hosting have also been reported for this species (Yang et al. 2017; Shen et al. 2019; Ouattara et al. 2023; Rifkin et al. 2023). In general, the competitive potential of alien *Ipomoea* species has been attributed to their fast growth and regeneration capacity (Sparkes and Panetta 1997; Norsworthy and Oliver 2002; Pagnoncelli et al. 2017; Averill et al. 2022; Randall 2012). *Ipomoea triloba* is a troublesome weed in many crops in the Philippines, Sri Lanka, Bangladesh, India, and Indonesia (Moody 1989; Holm et al. 1997). Reported crop losses due to different *Ipomoea* species vary from 25–90%, depending on their population density (Howe and Oliver 1987; Defelice 2001; Rizzardi et al. 2004; Price and Wilcut 2007; Bhattacharjee et al. 2009; Averilla et al. 2022; Pazzini et al. 2022). The *Ipomoea* species are ranked among the most troublesome weeds in cotton and soybean in the USA and Japan (Webster and MacDonald 2001; Norsworthy and Oliver 2002; Yasuda and Sumiyoshi 2010).

Management options

Non-chemical methods

The methods presented here rely on tools other than herbicides to reduce weed density and propagule pressure and hence the likelihood of new introductions, establishment, and spread. They include preventive, cultural, and physical (manual or mechanical) measures. Preventive measures to avoid field infestation include the use of certified crop seed and cleaning farm machinery after working in an infested field, especially during harvest (Yazlık et al. 2019; CABI 2024). However, the efficacy of each method depends on the species (perennial species are more persistent), invasion status, habitat characteristics, and its effectiveness (Verbrugge et al. 2019; Sohrabi et al. 2023c). Indeed, the seed capsules of *I. hederacea* plants with their wiry shoots tend to cling to the combs of harvesting machines, which can then infest other fields. *Ipomoea hederacea* seeds germinate throughout the summer, leading to new infestations in the same season, and reducing the effectiveness of mechanical control methods. Although these methods are effective against annual species such as *I. hederacea*, they have no residual control effect. In addition, this species can have more than one generation in a year. For example, plants that emerge early in the season can produce seeds that can germinate soon after shedding due to the lack of dormancy and post-ripening requirements (Kati and Giannopolitis 2006). These late germinating weeds are unlikely to cause yield reduction, but they will increase the soil seed bank if left unmanaged, thus perpetuating the infestation problem. Mowing did not minimize the competition from *I. triloba* at the V4 stage (fourth leaf collar is visible) of maize, while the weeding was more effective (Giraldeli et al. 2019).

A cultivation practice to reduce weed infestation during the growing season is the stale seedbed method, which is applied prior to sowing (Shaw 1996). It relies on early tillage and favourable weather conditions to encourage the germination of non-dormant weed seeds in the top layer of soil (a few centimeters below the surface). The emerging weeds are then killed by a shallow till (or by applying a broad-spectrum herbicide such as glyphosate, i.e. combining chemical and non-chemical control methods). A small but growing number of farmers in Greece are adopting the stale seedbed approach. However, unpredictable weather conditions in recent years have reduced the chances of success for this method. Early sowing of the crop will give it a competitive advantage over *I. hederacea*, which requires a relatively warm spring temperature (above 20 °C) and adequate soil moisture for germination.

The proposed management option for alien *Ipomoea* in natural areas, such as open forests (*I. indica* and *I. leucantha* in Iran, *I. indica* in Greece), would be a combination of several mechanical control methods supporting the regeneration of native plants. Early detection and long-term monitoring have also been emphasized for effective management (Pyšek and Richardson 2010; Simberloff 2011). Jones et al. (2021) suggested biological, cultural, and mechanical tactics to effectively control *Ipomoea* plants inhabiting disturbed areas.

In recent years, flaming control trials have been carried out as an alternative and innovative approach to chemical and mechanical control against *I. triloba* in cotton, corn and banana growing areas in Antalya province. The flaming successfully controlled *I. triloba* although it depended on the application time and number of repetitions (Arslan 2022; Doğru 2023; Saruhan 2024). The method was more successful on young plants and annual species, such as *I. triloba* (Tursun et al. 2017; Arslan 2022; Saruhan 2024). Therefore, flaming application as a physical control method could potentialy be used in habitats requiring control of annual *Ipomoea* species in the future.

Allelopathic plant extracts have also been used for the control of *Ipomoea*. In a study investigating the effects of ginger and turmeric extracts on the germination of *I. triloba* seeds, ginger extract reduced the germination by 97.3% and turmeric by 90.7% (Ece and Kitiş 2023). Some fungal diseases have shown promising potential for biological control of *Ipomoea* species (Soares and Barreto 2008; Nechet and Halfeld-Vieira 2019). In addition, biological control with some herbivores may also be promising. For example, leaf-feeding herbivores can potentially be used for biological control of *I. cairica* if they consume at least 50% of the leaf biomass (Li et al. 2012). Remote sensing can be used to map and monitor these species and thereby assist in their management. Early detection and monitoring will be facilitated by using a combination of satellites and unmanned aerial vehicles (Thürkow et al. 2024).

Chemical methods

Different broadleaf herbicides were used to minimize the negative impact of *Ipomoea* species on crop production. Imazapic and the combination of mesotrione with the mixture of diuron + hexazinone resulted in better control of *I. hederifolia*, *I. nil*, *I. quamoclit*, and *I. triloba* in dry and semi-wet seasons in Brazil (Correia 2016). To control *Ipomoea* species in sugarcane, the combination of PRE and POST herbicides (e.g., 2.4-D amine or sodium salt) has been recommended (Singh et al. 2012). Herbicide control is a common method to manage *I. hederacea*, *I. lacunosa*, *I. purpurea*, *I. hederifolia*, and *I. nil* in arable crops (Toledo et al. 2017; Jones et al. 2021). Control in soybean cultivation in Japan has been difficult due to intertillage and earthing up; soil-applied herbicides are less effective than foliar herbicides (Sumiyoshi and Yasuda 2011). Bentazon, fluthiacet-methyl as foliar herbicides in soybean have shown some efficacy against *I. coccinea*, but they are less effective in controlling *I. hederacea* (Shibuya et al. 2006; Sumiyoshi and Yasuda 2011). Imazamox ammonium salt, a newly registered herbicide, is effective in controlling *I. hederacea*, despite minor damage to soybean (Asami et al. 2021). Control of *I. cairica* efficacy in China was 98% at 4.06 g/l of ethephon (Sun et al. 2015).

In Greece, the control of *I. hederacea* with herbicides, which is still the most widely applied method of weed control in arable crops in the country, has proved to be rather difficult. Field experiments in maize with the post-emergence herbicides mesotrione, bromoxynil, nicosulfuron, rimsulfuron, and the mixture rimsulfuron+thifensulfuron applied at the recommended rate gave an initial control of *I. hederacea* of over 80%. However, this efficacy was later reduced due to resprouting or the emergence of new plants (Giannopolitis et al. 2004). Further pot experiments with the above treatments and the pre-emergence herbicides prometryn, fluometuron and alachlor showed good efficacy (>80%) four weeks after application, although the efficacy of the post-emergence herbicides was transient again due to resprouting. Similarly, in another set of field and greenhouse experiments, prometryn controlled 86% of the *I. hederacea* plants, while mesotrione reduced the fresh and dry weight of the weed by more than 80% (Drolia 2004). In this study, fluometuron and dimethenamid gave poor weed control, reducing the fresh or dry weight of *I. hederacea* by 50% and 30%, for each herbicide, respectively, while bentazon and oxyfluorfen provided moderate control (58–66%). It should be noted here that the pre-emergence herbicides prometryn and alachlor, and the post-emergence herbicide bromoxynil, are no longer registered for use in Greece. The post-emergence herbicide dicamba can provide effective control of *I. hederacea* in maize as has been demonstrated in pot experiments, although under field conditions, the weed's prolonged period of emergence during the cropping season re-established the problem. It is evident from the above that a combination of methods is required for effective and long-lasting control of *I. hederacea*. This includes cultural and mechanical measures supplemented by residual pre-emergence, and effective post-emergence herbicides (Giannopolitis et al. 2004).

In Türkiye, the lack of management programmes and registered herbicides for *I. purpurea*, *I. hederacea* and *I. triloba*, which are commonly found in cotton and maize fields (Muslu and Tepe 2016; Yazlık et al. 2018; Özkil and Üremiş 2020; Arslan and Kitiş 2021), has increased their abundances and impacts. For example, *I. triloba* is the second most important weed in terms of density (29 plants/m^2) and incidence (67%) in cotton production areas in the Antalya province (Arslan and Kitiş 2021). However, in recent years, the efficacy of some active ingredients against *I. triloba* has been investigated, and trifloxysulfuron sodium was found to be quite effective in cotton fields (Özkil et al. 2019; Arslan 2022).

In Iran, control is not direct but targeted with other broadleaf weeds. The infected fields are controlled by common broadleaf herbicides such as bentazon (thiadiazine group), trifluralin, ethalfluralin and pendimethalin (dinitroaniline group), envoke (trifloxysulfuron sodium) (Barati Mahmoodi et al. 2011; Gholamalipour Alamdari et al. 2016; Fakhari et al. 2020). The combination of tillage and herbicide application has recently been recommended to improve weed control in soybean and cotton fields (Gholamalipour Alamdari et al. 2016; Ghavi and Armin 2021). The correct time to control *I. purpurea* in croplands in Iran is suggested to be at the third or fourth leaf stage or at the latest before seed formation to limit its seed production and prevent regeneration of the seed bank (Abbasi et al. 2022).

In general, effective management plans require a multidisciplinary approach and stakeholder involvement (Woodford et al. 2016; Erazo et al. 2024). Prioritizing species, applying optimal long-term strategy, and sufficient economic resources to support the implementation are key elements of sustainable approaches (Epanchin-Niell 2017; García-Díaz et al. 2022; Kumschick et al. 2024).

Conclusions

All *Ipomoea* species generally have high environmental and socio-economic impacts, especially as agricultural weeds. The competitive ability of alien *Ipomoea* is expected to increase with climate change. Furthermore, the use of these species as ornamentals increases the risk of their rapid invasion and establishment in different habitats. Therefore, priority should be given to precautionary measures that minimize the risk of their invasion, such as including these species in quarantine plant lists or using certified crop seeds. In addition, farmers and the general public need to be made aware of the environmental and socio-economic impacts of *Ipomoea* species. As highlighted in our paper, the management of weedy *Ipomoea* taxa is particularly challenging in all three countries studied here and beyond. The lack of registered herbicides to control these species hinders the efforts to minimize the severity of their impacts. It is therefore imperative that non-chemical management options are developed, optimized, and combined with preventive measures, to reduce the risk of invasion and mitigate the negative impacts of alien *Ipomoea* species. Moreover, due to their ability to climb and reach heights of up to 2.0 m or more, along with its ivy structure and showy flowers, these species are popular ornamental plants. However, they can have serious impacts on many habitats, especially in agriculture. As a result, *Ipomoea* species can be considered relatively easy to be monitored. Therefore, future monitoring and distribution mapping, as evidenced in our study, is likely to be feasible, potentially involving citizen scientists. In addition, it is recommended to consider developing appropriate tools, machinery and equipment for innovative management approaches such as flame control and electromagnetic rays currently being implemented in trials in Türkiye. Finally, since this study reflects the distribution and impact status of the relevant taxa to a large extent, it also provides an idea for issues such as prioritizing the species to be included in the risk analysis.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

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Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.

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Supplementary material 1

Ipomoea taxa in Greece, Türkiye and Iran, their common names, main characteristics as alien plants and native ranges

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