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Research Article

Current distribution and status of *Arctotheca calendula* (L.) Levyns (Asteraceae) in Algeria and Tunisia (North Africa)

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Abstract

This study updates the distribution and status of *Arctotheca calendula* (L.) Levyns (Asteraceae, Cichorioideae) in continental North Africa (Algeria and Tunisia). Field surveys carried out mainly in northeastern Algeria (from 2021 to 2024) and northern Tunisia (from 2004 to 2023) by the first two authors, led to the identification of a total of 13 new localities (5 in Algeria and 8 in Tunisia), some of which are located far from the locations where the plant was previously reported by other authors. Our results showed that *A. calendula* spreads in a westward direction in Algeria from the first recorded occurrence (El Behaira pond). To the contrary, in Tunisia the species spreads towards the north, east and west from the first recorded occurrence (Sejnane). Currently, in both Algeria and Tunisia, the species colonizes exclusively wetlands, but a possible future expansion into other habitats, notably coastal dunes and beaches, cannot be ruled out. Additionally, the species is likely to spread into western Algeria as it was recently detected just 7 km from the border between Algeria and Morocco where it is widespread. To highlight this spread, a map of the current distribution of *A. calendula* within continental North Africa (mainly Algeria and Tunisia) and field images are provided; the possible negative impacts of the species are also discussed. As a result of this work, *A. calendula* can be defined as a species with high invasive potential in continental North Africa. Its invasion in Algerian and Tunisian wetlands requires the implementation of a management plan to control its further spread within these threatened ecosystems. Hand-pulling is, in our opinion, the best solution, but it needs to be implemented quickly before the species' range expands further, notably in Algeria.

Key words: alien species, Cichorioideae, invasion, meadows, Maghreb, management, negative effect, spread, vector of introduction

Introduction

Improved monitoring of plant biodiversity in continental North Africa, particularly in Algeria and Tunisia, has enabled researchers working in this field to publish dozens of works over the last ten years, some of which deal

with the discovery of new native species, while others focus on the establishment of new introduced species (see e.g. El Mokni and Verloove 2021, 2022; El Mokni 2023; Sakhraoui et al. 2023a, b, c; Sakhraoui 2023). Monitoring the population dynamics of alien plants is particularly important, as it can contribute to the early detection of invasions, and allowing implementing appropriate control strategies. However, undertaking this type of work can pose challenges, particularly in Algeria due to the country's size and the difficulties encountered in the field.

Within that framework, this study was carried out, in which we present new findings of a spreading alien species in North Africa (Algeria and Tunisia), i.e. *Arctotheca calendula* (L.) Levyns.

Arctotheca calendula is native to South Africa (Cape Province to Lesotho and KwaZulu-Natal) (POWO 2023), and has been accidentally (via contaminated seeds) or intentionally (as an ornamental plant) introduced into several parts of the world (CABI 2023) where it has become naturalized, notably California (POWO 2023), New Zealand and Australia, where it is considered a common weed of pastures and cultivated areas (Wood 1994; Weed of Australia 2023). In the northern part of the Mediterranean basin, the species has been reported as casual in Greece (Arianoutsou et al. 2010), naturalized in Spain (Aymerich and Sáez 2019), mainland France, Sardinia and Malta (Euro+Med PlantBase 2023), potentially invasive in Corsica (EPPO Global Database 2023), and its status has recently been changed from naturalized alien (Brundu et al. 2015; Galasso et al. 2018) to invasive alien in mainland Italy (Stinca et al. 2021).

In the southern part of the Mediterranean region, the species has only been reported as naturalized in Palestine and continental North Africa (POWO 2023). There, *A. calendula* has been recorded in Morocco, where it has been reported naturalized along the Moroccan shores of the Mediterranean sea and Atlantic ocean since 1987 (first records were made in the Kenitra region, northwestern Morocco) (see Vogt 1996; Valdés et al. 2002); in Tunisia, where few sporadic naturalized populations have been found in the Sejnane region in northeastern Tunisia (Le Floc'h et al. 2010), and more recently in Algeria, where a single locality has been recorded by Hamel et al. (2020) in El Tarf region in northeastern Algeria.

In the last years, new localities of the species have been recorded in continental North Africa (Algeria and Tunisia) following field surveys carried out by the first two authors of this article in northeastern Algeria and northern Tunisia. Here, we summarize new data about the distribution and status of *A. calendula,* showing the rapid spread of this species in continental North Africa. We also discuss the causes and consequences of this spread, and we propose appropriate control measures based on the information gathered and the situation of plant populations observed in the field.

Materials and methods

Arctotheca calendula was discovered during field surveys carried out in northeastern Algeria, notably in the wilayas (= districts) of Skikda and Annaba, between 2021 and 2024, and in northern Tunisia between 2004 and 2023.

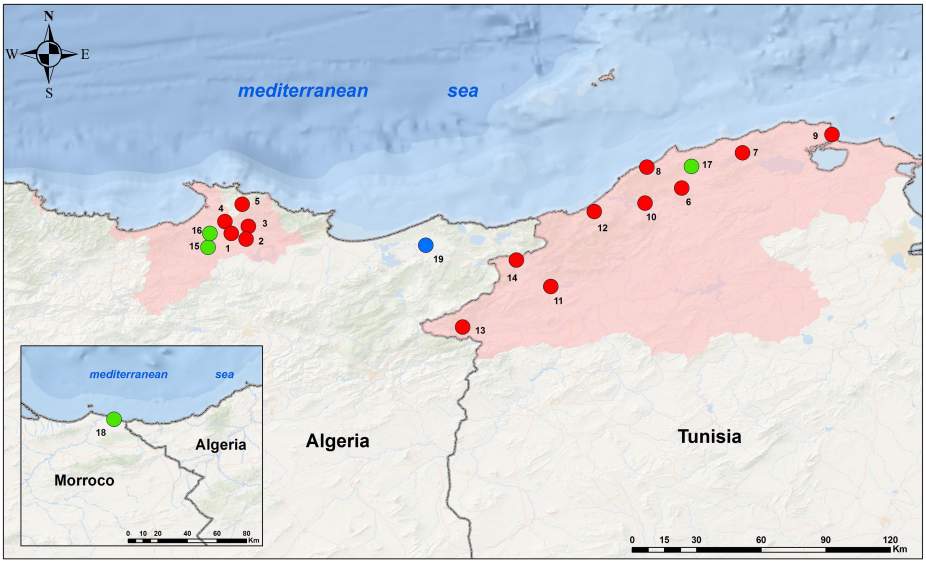


Figure 1. Prospected areas (pink) and distribution of *Arctotheca calendula* in Algeria and Tunisia with observations recorded between 2004 and 2023 from different data sources (dots). The numbers and different colors are according to data sources classification: red (numbers from 1 to 14 correspond to Table 1) = localities recorded in this study, green (numbers from 15 to 18) = localities recorded on iNaturalist, with the locality of Saïdia (small map, northeastern Morocco) 7 km from the Algerian-Moroccan border, blue (number 19) = locality recorded by other authors.

These surveys, conducted at least nine to ten times per season, so that each site was visited at least twice a year, covered a variety of habitats, including beaches, cliffs, wadi mouths, coastal dunes, lakes and temporary pools in the Guerbes-Sanhadja and Taleza wetlands (Algeria), roadsides and wet meadows in and around the Sejnane area, and in oak forest rangelands within the Mogods and Kroumiria zones (northern Tunisia), to monitor the population dynamics of previously recorded alien species (see e.g. El Mokni and Verloove 2021, 2022; El Mokni 2023; Sakhraoui 2023; Sakhraoui et al. 2023a, b, c).

The surveys extended over a large area (Figure 1), with several kilometers covered by car (200 km in Algeria, and around 500 km in Tunisia), but also on foot in some accessible areas, including the coastal dunes and beaches of Larbi Ben M'Hidi, Stora, Filfilla, Kef Fatima, Guerbes and El Rmila, the mouths of oueds such as oued Saf-Saf, oued Righa and oued El Kebir, and the lakes of Sidi M'hammed and Hadj Tahar, for Algeria, and the areas of Teskraia (Sejnane), Nefza, Aîn Sobh, Ras Rajel, the coastal dunes and the mouths of certain rivers of the Guelta Safra area, Berkoukech, Sidi Bader and the touristic area of Tabarka, forest paths, lands and roadsides in the Majen Chitana, Khroufa, Jab-Allah, Sidi M'hammed, Habiba, Aîn Draham, Babouch, Fernana, Sloul and Elbhira areas, for Tunisia.

Rapid identification of the species was carried out in the field using the Pl@ntNet identify application (https://identify.plantnet.org/fr) and then confirmed by consulting a number of bibliographical sources, such as McKenzie et al. (2011), Ghafoor and Bean (2015), Talavera and Talavera (2015), Tirgan et al. (2022) and PlantNet New South Wales (https://plantnet.rbgsyd.nsw.gov.au/cgi-bin/NSWfl.pl?page=nswfl&lvl=sp&name=Arctotheca~calendula). The description given in this article is based on specimens

observed in the field. When a new locality was discovered, co-occurring species and geographical coordinates were recorded. Further, seasonal monitoring was used to determine species' phenology and the degree of naturalization that was assessed according to Pyšek et al. (2004).

To determine the worldwide distribution of *A. calendula*, we consulted several databases and checklists, including APD (2023), Euro+Med PlantBase (2023) and POWO (2023). For gathering additional information on the distribution of the species in Algeria and Tunisia, a bibliographical search was first carried out on the iNaturalist platform (https://www.inaturalist.org/) and the GdB herbarium (https://gdebelair.com/) devoted to the Algerian flora, then extended to all the scientific literature reporting the species in continental North Africa, using keywords such as *Arctotheca calendula*, inventory, co-occurring flora, Algeria, Tunisia.

To assess possible future spread and impacts of the species in Algeria and Tunisia, we relied on its biological and ecological traits observed in the field as well as those cited in bibliographic sources, its invasion history in the Mediterranean region or regions with a Mediterranean climate, and the impacts of the species reported in the scientific literature.

Results and discussion

We found 13 new localities of *Arctotheca calendula* during field work, five were recorded in Algeria and eight in Tunisia; there, its persistence in the locality of Sejnane (i.e. the first locality previously reported in Tunisia by other authors) was also confirmed. The records are distributed over a wide area in northern Tunisia and a smaller area in northeastern Algeria (Figure 1).

The species seems to have extended its range to the west of the locality where it was first discovered in Algeria (El Behaira pond) by more than 130 km from Skikda, while it seems to have extended its range to the north, east and west of the first locality (Sejnane) recorded in Tunisia by more than 90 km from Hammam Bourguiba (northwestern Tunisia); emphasizing, on the one hand, its great ability to spread rapidly over long distances, and reflecting, on the other hand, its high invasive potential.

This study represents the second record of *A. calendula* in Algeria and in Tunisia.

Taxonomy, nomenclature and description of specimens encountered in the field

Arctotheca calendula (L.) Levyns, S. Afr. J. Bot. 8: 284 (1942) (Asteraceae) (Figure 2A–L).

Main synonyms : *Arctotis calendula* L., Sp. Pl. 2: 922 (1753); *Arctotis tristis* L., Sp. Pl. 2: 922 (1753); *Arctotis superba* L., Cent. Pl. II. 32 (1756); *Arctotis calendulacea* L., Syst. Nat., ed. 12. 2: 578 (1767); *Arctotis sulphurea* Gaertn., Fruct. Sem. Pl. 2(3): 439 (1791); *Arctotis speciosa* Salisb., Prodr. Stirp. Chap. Allerton 209 (1796); *Arctotis hypochondriaca* Willd., Sp. Pl., ed. 4 [Willdenow] 3(3): 2348 (1803); *Cryptostemma calendulaceum* (L.) R.Br., Hort. Kew., ed. 2

[W.T.Aiton] 5: 141 (1813); *Cryptostemma hypochondriacum* R.Br., Hort. Kew., ed. 2 [W.T.Aiton] 5: 141 (1813); *Cryptostemma runcinatum* R.Br., Hort. Kew., ed. 2 [W.T.Aiton] 5: 141 (1813); *Cynotis hypochondriaca* Hoffmanns, Verz. Pfl.-Kult. Nachtr. 2: 98 (1826); *Alloiozonium arctotideum* Kunze, Linnaea 17(5): 572 (1844); *Cryptostemma calendula* (L.) Druce, Bot. Exch. Club Brit. Isles Rep. 3(5): 416 (1914); *Arctotheca calendulacea* (R.Br.) K. Lewin, Repert. Spec. Nov. Regni Veg. Beih. 11: 49 (1922).

It is a rosette-forming perennial herb, up to 40 cm wide and 30 cm high. Taproot, usually short and slightly thick, branched, surrounded by several fasciculate roots, these sometimes longer than the taproot. Stems very short or longer, branching with age at the base, erect or often ascending, ridged, sometimes emitting adventitious roots at the nodes. Leaves petiolate, lyrate-pennatisect, rarely lyrate-pennatipartite, toothed, irregularly and deeply lobed with 2 to 6 pairs of lobes, green and slightly hairy on the upper side, white tomentose and densely hairy on the lower side, especially near the veins. Petioles sometimes purplish, often densely hairy. Capitula solitary and terminal, up to 5 cm (or more) in diameter, erect at flowering, ligulate, peduncles long, striated, green, sometimes densely covered with ± purplish hairs. Receptacle flat at fruiting, alveolate, glabrous, with pentagonal alveoli surrounded by a scarious, white crown. Involucral bracts imbricate, green, ciliate, the outer ones with a recurved apical appendage, linear or lanceolate, densely covered—especially on the margin—with hyaline moniliform hairs, the inner ones narrowly black margined. Ray florets 8–15 (Algeria) or 8–20 (Tunisia), sterile, ligules oblong, pale yellow in upper half, mostly darker yellow in lower half, greenish-purplish at the base. Disc florets bisexual, yellowish proximally, black distally. Anthers black. Style branches elliptical, yellowish. Achenes oblong-obovoid, dark brown, surrounded by copious brown woolly hairs, easily detached at maturity.

By checking some photos of confirmed specimens of *A. calendula* reported on iNaturalist in South Africa (https://www.inaturalist.org/observations?nelat=22.1254239&nelng=38.2216904&pag=3&place_id=any&swlat=-47.1313489&swlng=16.2816999&taxon_id=56024), and the description given by SANBI (2023), we found that South African populations differ from North African populations in terms of flowers: specimens from the South African populations have a greater number of ray florets (up to 22 florets), whereas the Algerians have a maximum of 15 florets and the Tunisians 20 florets.

However, although it is the only representative species of its genus in North Africa (Morocco, Algeria, Tunisia) (Dobignard and Chatelain 2011; APD 2023), it remains very difficult to identify in the field without flowers. Misidentifications and confusion are therefore possible with other common native species in Algeria and Tunisia, notably species of the genera *Centaurea*, *Hyoseris*, *Taraxacum* and *Urospermum*.

Arctotheca calendula can be confused with another South African species, *A. prostrata* (Salisb.) Britten, which is an unfertile, stoloniferous plant (see Hinojosa-Espinosa and Villaseñor 2015) with yellowish disc florets (Ghafoor and Bean 2015).

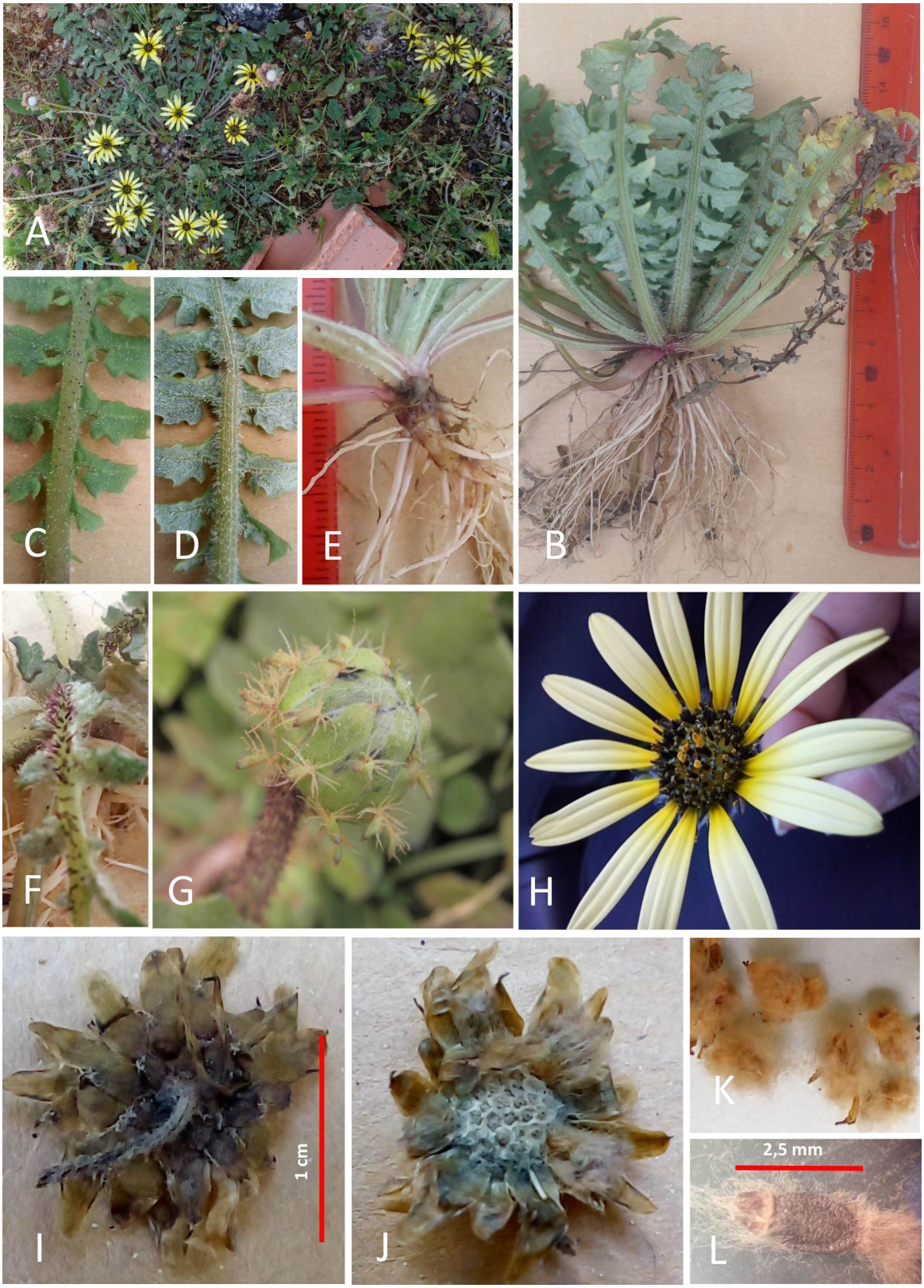


Figure 2. *Arctotheca calendula* in North Africa (Algeria and Tunisia). Flowering individuals along the roadside in Tacha village (Annaba, northeastern Algeria), 22nd April 2023 (A); aerial and underground parts of the plant collected in the El Zaouia locality (Skikda, northeastern Algeria), 7th January 2024 (B); hairy leaves, upper surface (C) and lower surface (D), 15th January 2024; root system with branched taproot surrounded by a few fasciculate roots, 15th January 2024 (E); purplish hairs on the upper surface of the petiole and main vein, 15th January 2024 (F); a flower bud with hyaline moniliform hairs, Nefza (Béja, northwestern Tunisia), 6th April 2015 (G); capitula with black center, 7th May 2023 (H); flat receptacle, lower surface (I) and upper surface with pentagonal alveoli surrounded by a scarious white crown (J), 15th January 2024; fruit with densely woolly indumentum, 22nd April 2023 (K); achene with 2 lateral ribs, 21st January 2024 (L). Photo (G) by R. El Mokni, all other photos by N. Sakhraoui.

Table 1. Geographic coordinates of recorded localities of *Arctotheca calendula* in North Africa (Algeria and Tunisia).

Id	Locality (Village, Douar) and date of observation	Municipality	Wilaya (=district)	Habitat	Population size	Occupied surface area	Coordinates (DD)		
							Lat.	Long.	Alti. (m)
Algeria									
1	El Zaouia village 17.03.2023, 22.04.2023	Ben Azzouz	Skikda	Uncultivated land, near to the houses, roadsides near to the meadows	Large population in flower and in fruit	100 m^2	36.875	7.35991	10
2	Tacha village 17.03.2023	Berrahal	Annaba	Roadside near to meadows	Small blooming population	6 m^2	36.8505	7.42199	19
3	Triaat village 22.04.2023	Berrahal	Annaba	Roadsides and the edges of sidewalks	Large population in flower and in fruit	40 m^2	36.9037	7.43138	35
4	Between Triaat and Bouchachia 22.04.2023	Berrahal	Annaba	Roadside at a few meters from pastures and crops	Small population in flower and in fruit	6 m^2	36.9243	7.33367	18
5	Bouchachia village 22.04.2023	Berrahal	Annaba	Roadside	Small flowering and fruiting population	9 m^2	36.9961	7.40616	176
Tunisia									
6	Sejnane village 09.04.2004, 29.04.2012	Sejnane	Bizerte	Roadsides and wet meadows	Large population in flower and in fruit	1000 m^2	37.0644	9.24222	127
7	Teskraia village 01.04.2014	Sejnane	Bizerte	Roadsides	Large population in flower and in fruit	400 m^2	37.2111	9.49694	66
8	Majen Chitana, Sidi Mechreg village 03.05.2017	Sejnane	Bizerte	Roadsides in a cork oak forest	Small, sporadically flowering population	1000 m^2	37.1511	9.09694	179
9	Bizerte North village 03.03.2018	Bizerte North	Bizerte	Roadsides and wet meadows	Large population in flower and in fruit	200 m^2	37.2875	9.87055	5
10	Nefza village 06.04.2015	Nefza	Béja	Roadsides near wet meadows	Large population in flower and in fruit	1000 m^2	37.0013	9.08972	27
11	Fernana village 29.04.2012	Fernana	Jendouba	Roadsides	Large population in flower and in fruit	2 ha	36.6533	8.69555	286
12	Ras Rajel village (Guelta-Safra locality) 15.04.2015	Tabarka	Jendouba	Roadsides and wet meadows	Very large population in flowers and fruits	25 ha	36.9661	8.87750	30
13	El Feidja (Douar Rehim) 11.06.2021	Ghar Dimaou	Jendouba	Roadsides and wet meadows	Small population with flowers and fruits	1000 m^2	36.4831	8.32713	420
14	Hammam Bourguiba (Sloul village) 19.06.2023	Aîn Draham	Jendouba	Roadsides and wet meadows	Small, sporadically flowering and fruiting population	100 m^2	36.7630	8.55166	155

Locations and population sizes recorded during this study

In Algeria, the largest populations have been observed in the villages of El Zaouia (wilaya of Skikda) and Triaat (wilaya of Annaba), where hundreds of individuals have been recorded. In Tunisia, on the other hand, populations are much larger, covering large areas of up to 25 ha in the Ras Rajel region (wilaya of Jendouba).

Details of this section are shown in Table 1.

Phenology

In Algeria, the species flowers from mid-March to early June. In Tunisia, flowering is also mainly in spring, between April and May, but can extend into June in years with late rains. Targeted surveys carried out by the first author on 21st August 2023 revealed total desiccation of individuals, which was also observed in Tunisia by the second author of this work.

In the study area, the plant behaves like a perennial. The above-ground parts die back by mid-summer and grows back with the first rains of autumn.

Reproduction in the Algerian and Tunisian populations takes place via seeds, which were harvested during the maturation phase in large quantities in Algeria at the end of March 2023, and in Tunisia at the end of April 2012.

In the native range, flowering time is from July to April (SANBI 2023) and it is described as perennial (Herman et al. 2017).

Habitats, pathway of introduction, distribution and status in Algeria and Tunisia

The populations of *A. calendula* observed in Algeria within Skikda and Annaba regions grow on alluvial soil among native species such as *Avena* sp., *Bellis annua* L., *Borago officinalis* L., *Carduus* sp., *Cerinthe major* L., *Cladanthus mixtus* (L.) Chevall., *Cynodon dactylon* (L.) Pers., *Echium* sp., *Erodium moschatum* (L.) L'Hér., *Euphorbia helioscopia* L., *Lolium perenne* L., *Lysimachia arvensis* (L.) U. Manns & Anderb., *Plantago coronopus* L., *P. lanceolata* L., *Salvia verbenaca* L. and *Trifolium repens* L. They most often where observed on roadsides and in pastures and some populations extend over long distances. Relicts of Mediterranean maquis are also common in the study area, which are characterized by the presence of several native shrub species, such as *Arbutus unedo* L., *Calicotome spinosa* (L.) Link, *Crataegus monogyna* Jacq., *Erica arborea* L., *Pistacia lentiscus* L., *Myrtus communis* L., *Olea europaea* L. subsp. *europaea* and *Rubus ulmifolius* Schott.

The recorded localities belong to the wetlands of Numidia (i.e. K3, biogeographical sector determined in Algeria by Quézel and Santa (1962)), which are characterized by temporary ponds and/or permanent freshwater lakes (Figure 3A), locally called in the Skikda region "Garâa". These natural reservoirs are used by local residents for crops irrigation. Currently, *A. calendula* seems to be missing in other surveyed habitats listed in material and methods, and it also seems to be absent in the wetlands of Taleza (Municipality of Collo) located west of the capital of the wilaya of Skikda where field surveys carried out on 22nd March 2023 by one of the authors (H. Raïs) have yielded no findings.

In Tunisia, habitats of the occurrences of *A. calendula* are also wet meadows with hygrophilic vegetation (Figure 3B) within cork oak forests or areas bordering these ecosystems which are characterized by loamy hydromorphic soils with gley to pseudogley, and a vegetation particularly rich in herbaceous plants. The main accompanying species of *A. calendula* are *Bellis annua* L., *Chamaemelum fuscatum* (Brot.) Vasc., *Eryngium pusillum* L., *Melilotus sulcatus* Desf., *Mentha pulegium* L., *Ochlopoa infirma* (Kunth) H. Scholz, *Parapholis incurva* (L.) C. E. Hubb., *Plantago bellardii* All., *P. coronopus* L., *Sherardia arvensis* L., *Squilla numidica* Jord. & Fourr., *Trifolium scabrum* L., *T. subterraneum* L. and *T. tomentosum* L. These meadows are mainly grazed by cattle as long as they are well-watered, otherwise by goats and sheep.

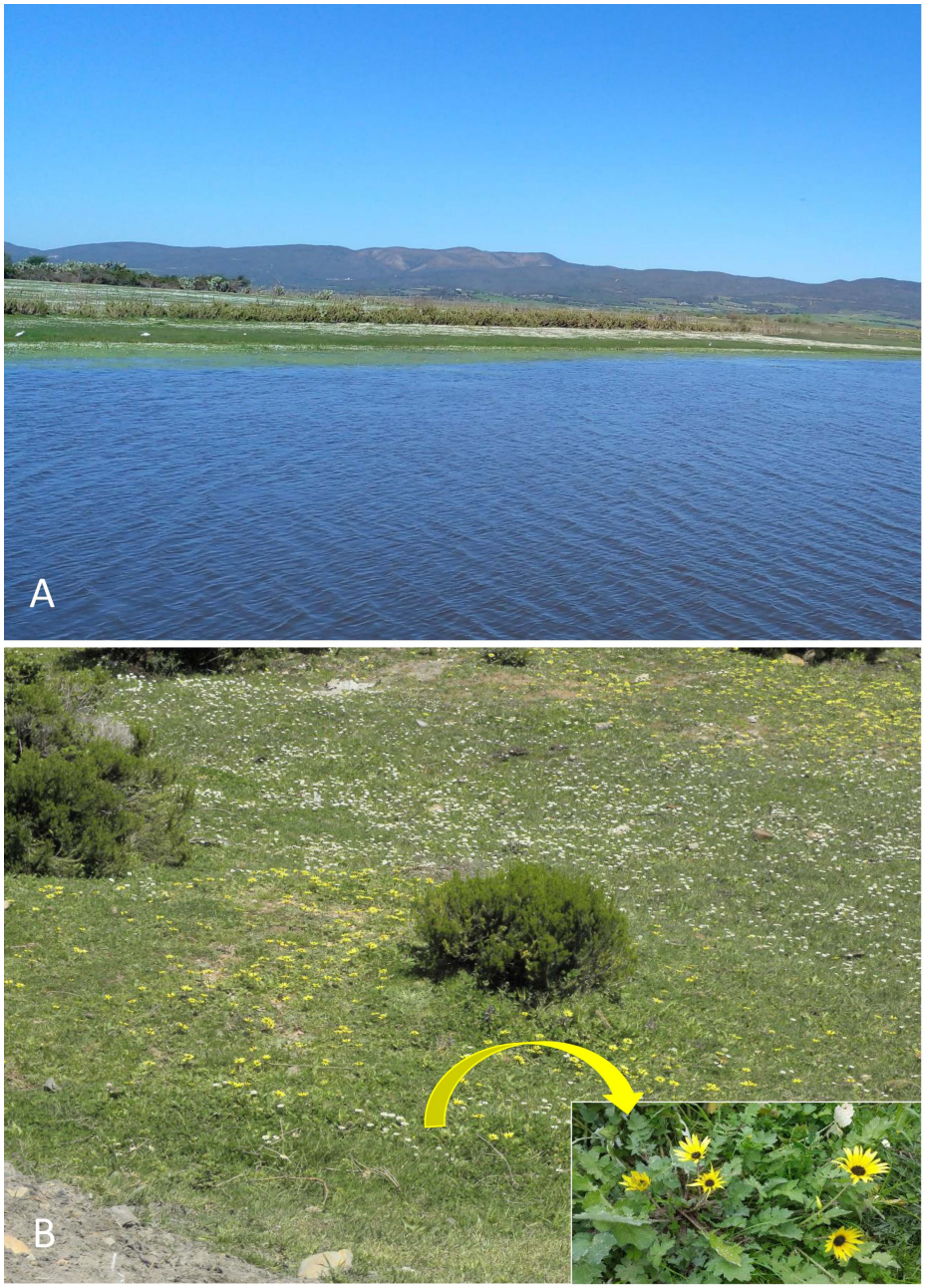


Figure 3. Habitat of *Arctotheca calendula* in North Africa (Algeria and Tunisia). Wetland of Guerbes-Sanhadja (Skikda, northeastern Algeria) where the species was discovered, 17th March 2023 (A), photo by N. Sakhraoui; a meadow in a wetland invaded by a large population of *A. calendula* mixed with native flora (Tabarka, northwestern Tunisia), 15th April 2015 (B), photo by R. El Mokni.

The localities registered in Tunisia belong to the biogeographical sectors of Kroumiria, Mogods and North-East (i.e. K, M and NE sensu Cuenod (1954) and Pottier-Alapetite (1979–1981)) which, like the Algerian study area, are characterized by the presence of swamps and ponds, particularly in the region of Sejnane, Majen Chitana and Bizerte.

Arctotheca calendula was first observed and collected in 2018 in Algeria by Hamel et al. (2020) in El Kala National Park (wilaya of El Tarf, eastern part of the wilaya of Skikda and Annaba) on the banks of the El Behaira pond. The introduction of the species in Algeria is probably recent because

the localities where it has been recorded, are among the floristically best-studied sites in Algeria due to their biological richness and ecological interest. It is therefore unlikely that the species would have gone unnoticed by the various researchers who have meticulously prospected these places, including the eminent botanist G. de Bélair (https://gdebelair.com/). This is also the case in other neighbouring countries, notably Tunisia where it seems that the species has been introduced only since the 1970s with clover seed lots imported from Australia (Le Floc'h et al. 2010). However, the pathway of introduction in Algeria is unknown, but it seems plausible that it was accidentally introduced with contaminated peanut seeds (Hamel et al. 2020), as the species is not used for the ornamental purpose in Algeria (see Sakhraoui 2021).

Possibly, the long-distance spread of *A. calendula* through the invaded wetlands in Algeria may have been facilitated by wintering avifauna that crosses the region in large populations (see e.g. Metallaoui and Houhamdi 2010; Loucif et al. 2020). Waterfowl have also been implicated as one of the main pathways of introduction of *A. calendula* into Iran where it was recently discovered and reported as established in the north of the country (see Tirgan et al. 2022).

In Tunisia, however, secondary dispersal of *A. calendula* is probably done by sheep and goats, water (through streams) and wind facilitated by the presence of well-developed pappus. These vectors are probably also involved in short-range dispersal in Algeria.

Hamel et al. (2020) do not clearly mention the status of the species in the El Kala region, but it is understood from the figure and information reported by these authors, that the species is well established in the locality, since it mixes with native species occupying an area of 100 m^2, and therefore can be considered as naturalized. In El Tarf region, the species colonizes the same habitat as the populations recorded in the regions of Skikda and Annaba. Interestingly, *A. calendula* was neither mentioned in the index of the flora of North Africa (Dobignard and Chatelain 2011), in the GdB herbarium (https://gdebelair.com/), nor in the alien flora of Algeria (Meddour et al. 2020); however, two records in the wilaya of Skikda are reported on iNaturalist (https://www.inaturalist.org/observations/44299333, https://www.inaturalist.org/observations/115129904), which were recorded respectively in April 2020 and May 2022 in the Ben Azouz region. These two localities are located in the same region where our observations were made. Examination of the location map and photos published on the platform revealed that in one of the localities, the species occurs in a field and a grazed site; it also seems to form a large population mixed with native herbs. No other occurrences could be found in literature, limiting the current distribution of the species to northeastern Algeria.

However, the species should be searched for in the other wetlands of Algeria; research should focus on the areas bordering Morocco where *A. calendula* is common in several habitats (see Vogt 1996; Plant Biodiversity

of South-Western Morocco 2023). In fact, an occurrence was recorded recently (2nd May 2022) in the municipality of Saïdia (northeastern Morocco) on the Mediterranean coast (https://www.inaturalist.org/observations/116319650) only 7 kilometers to the west of the Algerian border.

In Tunisia, *A. calendula* has been recorded for much longer than in Algeria and is represented by much larger populations. It has been first recorded in 1977 in clearings and meadows in the Sejnane region (northeastern Tunisia), where it was considered naturalized (see Le Floc'h et al. 2010); this locality has been confirmed several times by the second author of this article between 2004 and 2012. A recent observation recorded on iNaturalist on April 2023 also confirmed the persistence of the species at this location (https://www.inaturalist.org/observations/110332653). As in Algeria, the species should be searched for in the other wetlands of Tunisia, especially those located in the east of the country (e.g. Ichkeul National Park and Bizerte Lake) where two new localities are reported in this study (Teskraia and Bizerte North) at about 70 km from Sejnane (for the locality of Bizerte North), likely indicating that the plant is spreading within the whole region.

Possible future spread and impacts of A. calendula *in Algeria and Tunisia*

Recently, *A. calendula* has spread in northeastern Algeria and northern Tunisia. We argue that especially in wetlands it may become invasive in Algeria in the future, favored by its biological traits, including reproduction (production of large quantity of seeds, large size and persistent seed bank, and an ecotypic variation for seed dormancy (Dunbabin and Cocks 1999; Ellery and Chapman 2000)), and dispersal characteristics (dispersed by different vectors, including wind, water, animals and human activities (Madon 1994; Brundu et al. 2015)). In addition to these biological traits, there is the climatic factor which is very favourable since it is similar to that of the native range, and its history of invasion recorded in some Mediterranean or Mediterranean climate regions such as Italy (Stinca et al. 2021) where it tends to invade coastal dunes, and California where it is widespread in grasslands (Mahoney and Mckenzie 2008; Calflora 2023; CAL-IPC 2023).

In its native range, the species colonizes Acacia-wooded grassland, dry grassland, on sandy soils, coastal areas or disturbed places, often as weed of roadsides and waste places (Herman 2013; Herman et al. 2017). However, in some areas of introduction, *A. calendula* colonizes a similarly wide range of habitats. In Morocco, for example, it was recorded on coastal sands, beaches and rocks, on river banks and dam ditches, and wetlands in *Pinus* forests (Vogt 1996; Dobignard 2009). Eighteen occurrences including an unconfirmed one were made there between March 2013 and May 2023 on the iNaturalist platform, distributed mainly along the Atlantic coast with some occurrences on the Mediterranean coast and inside the country.

In Sardinia (Italy), *A. calendula* was observed in rangeland with sparse oak-trees on acidic sandy soils, in an occasionally irrigated field on alluvial sandy soil, and in a disturbed garrigue that developed after a fire on nutrient poor granitic soil (Brundu et al. 2015); finally in Australia, the species colonizes pastures, crops, orchards, gardens, trails, disturbed sites and natural areas (e.g. coasts, grasslands, open forests), and has even been recorded in semi-arid areas and occasionally in Australian arid areas (Wood 1994; Weeds of Australia 2023). *Arctotheca calendula* is therefore endowed with a remarkable ecological plasticity, which allows us to predict a future extension beyond the Algerian and Tunisian wetlands habitats, especially in coastal dunes and beaches present in the study area within a few hundred meters of the Algerian localities.

According to Véla and Benhouhou (2007) and Véla (2018), the wetlands of northeastern Algeria (encompassing the Guerbes-Sanhadja plain (a Ramsar site, wilaya of Skikda), and the ponds of eastern Numidia (wilaya of El Tarf)), and those of northeastern and northwestern Tunisia (mainly in the Mogods and Kroumiria), host a rich and original native vascular flora, and are therefore classified as hotspots of plant biodiversity on the southern shores of the Mediterranean basin.

These habitats are already subject to several threats, including the extension of agriculture and pastoral activity, increased drought and fires, which have particularly increased as a consequence of climate change in the last decade (see Ghrabi-Gammar et al. 2009; Ferchichi-Ben Jamaa et al. 2010; Toubal et al. 2014; Sakhraoui et al. 2020). Grazing by cows is widely practiced in these regions where there are vast meadows. The spread of *A. calendula* could therefore have a double negative effect, environmental, on the one hand, by causing the loss of biodiversity, and economic on the other hand, by causing the loss of the quality of natural fodder resources, which would generate serious socio-economic repercussions, especially on local populations.

Indeed, the scientific literature reports that this species can seriously threaten native plant communities due to competition, particularly in coastal grasslands and riparian zones (Brundu et al. 2015). Further, the dense populations of *A. calendula* can negatively affect pasture quality (Conning et al. 2011); it can also be poisonous to herbivores, through accumulating potentially toxic levels of nitrate. Young plants are particularly involved in the threat of poisoning, which is especially serious for sheep (Fairnie 1969). When consumed by livestock, this may cause reduced weight (Pethick and Chapman 1991), and it may negatively affect milk or meat flavor (Matthews et al. 1999; Dowling et al. 2000).

Conclusions

We show that *A. calendula* is currently spreading in the wetlands of northeastern Algeria and northern Tunisia. This spread is worrying and warrants immediate action. Application of herbicides should be avoided, especially as the species possesses resistance against the most commonly used herbicides such as photosystem-I inhibiting herbicides (paraquat and diquat)

and Glyphosate (see Khalil et al. 2021); thus, other control methods such as hand-pulling, should be applied.

The cost of this manual method could be greatly reduced if farmers and peasants were involved in the operation after having been made aware of the negative impacts caused by the species. On the other hand, this easily applicable control method could yield very encouraging results, especially in Algeria, where *A. calendula* is still rare. Although interventions of this kind, targeting a single species, are rarely undertaken in Algeria or Tunisia, we believe that they offer a great potential for halting the spread of invasive alien plant species and thus help to preserve ecosystems. Management has also to be continued once the last individual of a population has been eliminated, to avoid re-emergence from the persistent seed bank.

Finally, according to the criteria of Pyšek et al. (2004), *Arctotheca calendula* can be considered as invasive in Tunisia and potentially invasive in Algeria.

Author's contribution

Research conceptualization: Nora Sakhraoui; sample design and methodology: Nora Sakhraoui and Ridha El Mokni; investigation and data collection: Nora Sakhraoui, Ridha El Mokni and Hichem Raïs; data analysis and interpretation: Nora Sakhraoui, Ridha El Mokni and Azzedine Hadef; funding provision: Franz Essl; writing: Nora Sakhraoui and Franz Essl; review: Franz Essl, Ridha El Mokni and Filip Verloove.

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