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The North American weed *Amaranthus tuberculatus* (Amaranthaceae) new to Portugal: previously overlooked or spreading rapidly?

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The North American weed *Amaranthus tuberculatus* (Amaranthaceae) new to Portugal: previously overlooked or spreading rapidly?

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Running title: *AMARANTHUS TUBERCULATUS* NEW TO PORTUGAL

Abstract – The dioecious species *Amaranthus tuberculatus* (Moq.) J.D.Sauer, native to North America and a major weed of agricultural fields and riparian habitats, was discovered on the banks of the Tagus (Tejo) River in the late summer of 2024, apparently for the first time in Portugal. The species occurs here in exceptionally large numbers, with probably tens of thousands of plants, and in numerous locations on the sandy and gravelly banks of the river in the Ribatejo area, roughly between Azambuja and Azinhaga, over a distance of about 60 kilometers. It may also occur further upstream, where no prospecting has been carried out but where suitable habitats are also available. Considering its current distribution and the number of plants observed, the species has either been present in the region for a long time but has been overlooked (although no older observations could be found on e.g. GBIF or iNaturalist, not even under other amaranth species names), or it is indeed a recent introduction that is spreading very rapidly. However, it can certainly be considered an invasive species. Here, the current naturalized range of the species in Europe and the Mediterranean area is critically reevaluated. Although the species is known from relatively many countries, it is currently only naturalized with certainty in Israel, Italy, Croatia, Serbia and now Portugal. The species is described and illustrated and a local distribution map is presented; notes on its ecology are also given.

Keywords: amaranth, dioecious species, invasive plants, naturalization, riparian habitats, Tagus River

Introduction

Amaranthus L. (Amaranthaceae) accommodates 65–70 species that are mostly confined to the tropics, subtropics and warm-temperate regions of the world. Approximately half of the species are native to the Americas (Mosyakin and Robertson 2003, Iamonico 2015) while the rest are native to Africa, Asia and Europe (e.g. Hassan et al. 2022, Raus 2022). The genus is economically important because quite a few species are used for various purposes, e.g. as ornamentals, for medicinal purposes or as crop plants (pseudocereals, vegetables) (Das 2016). On the other hand, the genus includes numerous agricultural weeds that are harmful to various crops (very numerous references, e.g. Bayón 2022). Both monoecious and dioecious species occur, but the distribution of the latter is limited to North America. For sexual reproduction, the dioecious species require both male and female individuals in their introduced range; nevertheless, several of these dioecious species have proven to be very troublesome weeds, in particular *A. palmeri* S.Watson (e.g. Torra et al. 2020, Sukhorukov et al. 2021) and *A. tuberculatus* (Moq.) J.D.Sauer (incl. *A. rudis* J.D.Sauer). The latter species, also referred to as the waterhemp complex, has been known as a major weed pest in corn and soybean fields in the U.S.A. (Steckel 2007) but is increasingly recorded as a weed elsewhere in the world as well.

Whereas the species is mainly harmful to agricultural crops in its area of origin, in Europe and the Mediterranean area it mostly occurs in more natural dynamic habitats, particularly on exposed riverbanks (Soldano 1982, Rimac et al. 2020). It is now listed on the EPPO A2 List of pests recommended for regulation as quarantine pests in the European Union (EPPO 2024).

In Portugal, the genus *Amaranthus* is possibly insufficiently known. According to Carretero (1990) the following species have been reliably recorded there: the probably native species *Amaranthus blitum* L. and *A. graecizans* L. and the introduced species *A. albus* L., *A. blitoides* S.Watson, *A. deflexus* L., *A. hybridus* L., *A. hypochondriacus* L., *A. muricatus* (Moq.) Hieron., *A. powellii* S.Watson, *A. retroflexus* L. and *A. viridis* L. Domingues de Almeida and Freitas (2006) subsequently added two further non-native species: *A. caudatus* L. and *A. cruentus* L., while a record of *A. crispus* (Lesp. & Thévenau) J.M.Coult. & S.Watson (Euro+Med Plantbase 2025) requires confirmation. No dioecious species are known.

During recent fieldwork in the Tagus valley in the Ribatejo area, in the late summer of 2024, dioecious plants greatly similar to plants that the author knew as *Amaranthus tuberculatus* from Northern Italy were found. Further research confirmed that they indeed belonged to that species. Although the species was extremely abundant, these seem to represent the first records in the wild in Portugal.

Materials and methods

The distribution data presented in this article are the result of fieldwork carried out by the author between 1 and 15 September 2024. On that occasion, numerous localities were explored in the wide Tagus River valley (Fig. 1), in the former Portuguese provinces of Estremadura and Ribatejo, especially in coastal and lowland areas. The main focus was on riparian and other damp habitats, such as rice fields. Anthropogenic, often urban habitats (such as roadsides, parks, etc.), agricultural fields, etc. were also explored.

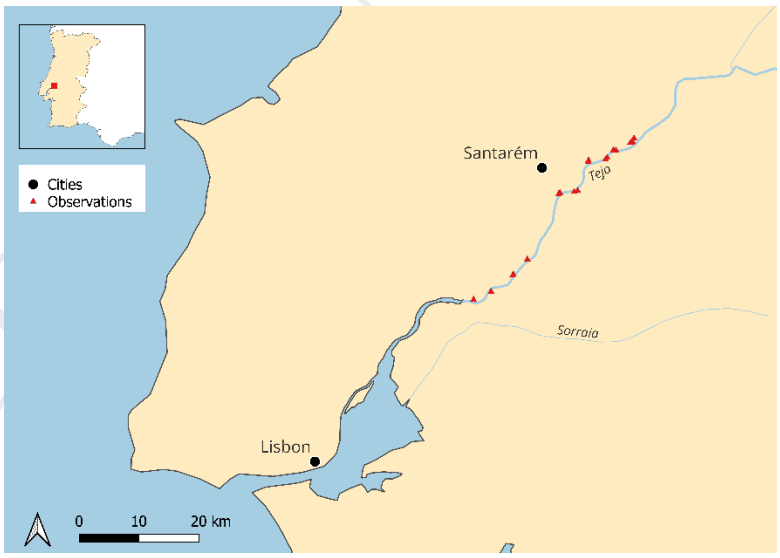

Fig. 1. Distribution of *Amaranthus tuberculatus* along the Tagus River in Portugal.

The species was identified using relevant literature sources, including Sauer (1955), Aellen (1959), Pratt and Clark (2001), Mosyakin and Robertson (2003) and Iamonico (2015). Voucher specimens were collected in several of the populations and these were deposited in the herbarium of Meise Botanic Garden, Belgium (BR), with some duplicates in the herbarium of

the University of Valencia (VAL). Specimens deposited in BR will in due time become available online at https://www.botanicalcollections.be. In addition, numerous photos were taken in several of the discovered localities. All records (including the photographs) were registered on the observation.org online platform (https://observation.org/), data which were subsequently also included in GBIF (Global Biodiversity Information Facility; https://www.gbif.org/).

To determine whether or not the species was known from Portugal, numerous relevant sources were consulted, e.g. Carretero (1990), Domingues de Almeida (1999, 2018, 2024) and Domingues de Almeida and Freitas (2006, 2012), as well as online sources such as iNaturalist (https://www.inaturalist.org/), GBIF, observation.org and Flora-On (https://flora-on.pt/).

The nomenclature in this paper follows Plants of the World Online (POWO 2024), which means that *A. rudis* is considered a synonym of *A. tuberculatus* (see also: Pratt and Clark 2001 and Mosyakin and Robertson 2003).

Results

Species description

Amaranthus tuberculatus (Fig. 2) is an annual, dioecious herb with erect, branched stems (or simple in smaller individuals), typically ranging from 1 to 2 meters in height (occasionally up to 3 m). Leaves have petioles measuring one-quarter to one-half the length of the blade. The blade shape varies from ovate or obovate proximally, and oblong, elliptic, or narrowly lanceolate distally, measuring 1.5–15 × 0.5–3 cm. The base is cuneate, margins are entire, and the apex ranges from obtuse or rounded to acute. Inflorescences are terminal, forming linear spikes or panicles that may occasionally be interrupted. Pistillate flowers feature bracts 1–2 mm long, with absent or rudimentary tepals (1–3 mm). Style branches are more or less erect, and stigmas number three. Staminate flowers have bracts with an inconspicuous to prominent midrib, 1–2 mm long, with an acuminate to short-subulate apex. There are five tepals, sometimes with prominent midribs excurrent as rigid spines, measuring 2–3 mm, with apex shapes varying from obtuse to acute, acuminate, or indistinctly mucronulate. Stamens also number five. Utricles are dark to reddish-brown, unribbed, and vary from obovoid to subglobose, 1.5–2 mm in size, with thin, nearly smooth to irregularly rugose surfaces. They may be indehiscent, irregularly dehiscent, or regularly dehiscent. Seeds are dark reddish-brown to dark brown, shiny, and measure 0.7–1 mm in diameter (adapted from Mosyakin and Robertson 2003).

Fig. 2. *Amaranthus tuberculatus* on the banks of the Tagus River in Santa Iria da Ribeira de Santarém, 3 September 2024. As is often the case, the species is accompanied by *Persicaria pensylvanica*, another American invasive weed (**a**). Female (left) and male (right) individuals in Pombalinho, 11 September 2024 (**b**). In Almeirim, 3 September 2024. The morphological variation of the species is great, especially regarding the colour and size of the plants, the branching pattern of the inflorescence, etc. (**c**).

Native and critical revision of the secondary distribution

Amaranthus tuberculatus is native to North America. The original area may have been limited to the region from the north of Missouri and Tennessee to the Great Lakes. As a major weed of agricultural fields and other disturbed habitats, it is now introduced in many parts of North America far outside its original range (Mosyakin and Robertson 2003). During the 20th century, the species was unintentionally introduced into other continents. It has been naturalized in Japan since 1959 (Egawa and Koyama 2023), potentially representing the oldest naturalized populations outside of America. The species was also repeatedly introduced into Europe and the Mediterranean area, with its first recorded introduction occurring in Austria in 1949 (Aellen 1959). Meanwhile, the species has been observed in numerous European countries: Austria, Belgium, Bosnia and Herzegovina, Croatia, Czech Republic, Denmark, Finland, Germany, Great Britain, Israel/Palestine, Italy, Jordan, the Netherlands, Romania, Russia, Spain, Sweden, Syria and Ukraine (Euro+Med Plantbase 2025). In addition, *A. tuberculatus* is also known from Switzerland (EPPO 2020). It should be noted, however, that in the vast majority of these countries, the species is an ephemeral alien that depends on the repetitive supply of seeds, especially in port areas. Although the EPPO Pest Risk Analysis is recent (EPPO 2020), its status

in some countries needs to be reevaluated. First of all, the species is now also known from Croatia and Serbia, where it is naturalized in the Sava River valley (Rimac et al. 2020, Tabašević et al. 2020). As this river forms the border between Croatia and Bosnia and Herzegovina, *A. tuberculatus* is in all probability naturalized in the latter country as well, recently having been reported (from another region) as a casual alien (Maslo et al. 2020). In some countries, the species was reported by EPPO (2020) as being in the process of naturalization, but this needs qualification. In Spain, the species was only seen once, in 2011, near grain silos in Palos de la Frontera (Sánchez Gullón and Verloove 2013). No mention was made of possible naturalization by the authors and, at least for now, the species is considered a casual alien in Spain. In the Netherlands, *A. tuberculatus* has occasionally been recorded on sandbars of the Meuse and Waal Rivers, which are a very suitable habitat for the species. However, based on current knowledge, only female plants have been discovered so far, with no seeds observed. In addition, the most recent sighting dates back to 2018 (https://waarneming.nl/). Given the frequency of surveys in the area, this suggests that the species has not (yet) managed to establish a permanent presence in the Netherlands. For Israel, on the contrary, the species was reported as being only locally established by EPPO (2020). However, the species has made rapid progress in recent years and has spread over a large part of the territory, both along rivers and roadsides and in agricultural crops. In addition, herbicide-resistant populations have also been detected (Roth et al. 2023). The status of the species in Romania is unclear according to EPPO (2020). The species is known from the port of Constanta, where it only temporarily persisted, and the delta of the Danube River. Although the latter location provides suitable habitats, it has not been observed there in recent years (comm. C. Sîrbu, November 2024).

In conclusion, based on the available data, *A. tuberculatus* is currently only established in four Mediterranean countries - Israel, Italy, Serbia and Croatia. The oldest established populations are from **Israel** where the species has been known since 1970 (Danin and Liston 1986), first from exposed lake margins in the Upper Jordan area. As mentioned, the species has now become a widespread and difficult-to-control weed. The status of the species in the neighboring countries of Jordan and Syria is unclear; the species may also have become naturalized there, but this needs to be confirmed. In **Italy**, the species has been known since 1975 from riparian habitats, first from the Po River (Soldano 1982) but in the intervening years the species has spread to other river systems in the northern half of Italy. It is now considered invasive in four regions (Lombardy, Emilia-Romagna, Veneto and Marche) and naturalized or casual in four others (Piemonte, Friuli Venezia Giulia, Tuscany and Trentino-Alto Adige) (Iamonico 2015). *A. tuberculatus* was more recently discovered along the banks of the Sava River, first in Serbia in 2016 (Tabašević et al. 2020) and later in Croatia in 2019 (Rimac et al. 2020). Considering its wide distribution in both countries, the species has at least become naturalized there, not to say invasive.

The species is here reported for the first time in the wild from **Portugal**. These are apparently the first naturalized/invasive populations in Europe outside the Mediterranean area (Serbia has no Mediterranean coastline but is biogeographically and climatologically part of it). Some previous Portuguese findings are documented on GBIF but these relate to plants that were formerly cultivated in the Botanical Garden of Coimbra. *A. tuberculatus* was discovered on 2 September 2024 on sandbanks of the Tagus River upstream of Porto de Muge (Valada). During the following days, more targeted searches were carried out for the species, both upstream and downstream of this location. It should be noted that downstream, exposed sand and mud banks (and therefore suitable habitats) are hardly present. Large parts of the river are also inaccessible or barely accessible. Nevertheless, *A. tuberculatus* was found at numerous locations, roughly between Azambuja and Azinhaga, over a distance of approximately 60 kilometers (Fig. 1). The further upstream, the more numerous the species was, especially from Santarém onwards. Near Azinhaga, it also grew abundantly along the lower stretch of the Almonda River, a tributary of

the Tagus, near its confluence with the Tagus. It is very likely that *A. tuberculatus* also occurs further upstream, but no prospections were carried out there. An overview of records is available as Supplementary Material (On-line Suppl. Tab. 1).

The following herbarium collections were made:

1. Valada, Porto de Muge, Rio Tejo, upstream of Ponte Rainha Dona Amélia, sand bank of the river, about 15 individuals, a very invasive but not previously recognized weed on the banks of the Tejo (male individual in this collection), 02.09.2024, *F. Verloove* 15221 (BR0000027058992V, dupl. VAL);
2. Chamusca, Vale de Cavalos, Rio Tejo, sand bank of the river, male individual in this collection, 03.09.2024, *F. Verloove* 15227 (BR 0000027058978V);
3. Chamusca, Vale de Cavalos, Rio Tejo, sand bank of the river, very common, female individual in this collection, 03.09.2024, *F. Verloove* 15228 (BR 0000027058954V);
4. Almeirim, Rio Tejo near sand extraction company, sand bank of the river, very common, male individual in this collection, 03.09.2024, *F. Verloove* 15231 (BR0000027058930V);
5. Almeirim, Rio Tejo near sand extraction company, sand bank of the river, very common, female individual in this collection, 03.09.2024, *F. Verloove* 15232 (BR0000027058947V);
6. Azinhaga, Rio Almonda near its junction with Rio Tejo, dried out river bed, very common, 11.09.2024, *F. Verloove* 15257 (BR 0000027058770V).

Habitat and ecology

In its natural range, *Amaranthus tuberculatus* is found in various types of wet habitats, such as margins of rivers, ponds, marshes, lakes and creeks as well as in disturbed habitats, such as agricultural fields, roadsides and railroads (Mosyakin and Robertson 2003). It is mainly in agricultural crops and in other disturbed habitats that the species has become a major weed, both in its native area and far beyond.

In the newly discovered secondary range in Portugal, *A. tuberculatus* is nearly exclusively found on the sand and gravel riverbanks (Fig. 2a), in particular the Tagus and Almonda Rivers. It is striking that, in most localities, the species is completely absent outside the actual riparian zone, despite its massive occurrence along the banks. Although the Tagus is bordered by vast agricultural areas with a lot of maize, a crop in which the species occurs as a noxious weed in the U.S.A. (e.g. Vyn et al. 2006, Soltani et al. 2009, Hamberg et al. 2024), it was not observed in any of these fields. Only in the vicinity of Azinhaga was the species seen, and then sporadically along the field roads, a few hundred meters away from the river.

On the sand and gravel bars, *A. tuberculatus* was found in several plant associations, ranging from annual dwarf communities on sand near the waterline (*Nanocyperion* Koch 1926 alliance), to associations of slightly taller annual species, further from the waterline and usually developed on organo-mineral sediments (*Bidention tripartitae* Nordhagen ex Klika et Hadač 1944 alliance). It also occurs on the edges and in clearings of the alluvial forest that is mostly composed of willows (*Salicion albae* Soó 1951 alliance). All these plant communities are characterized by the abundant presence of other non-native species, such as *Cyperus esculentus* L., *Dysphania ambrosioides* (L.) Mosyakin & Clemants, *D. pumilio* (R.Br.) Mosyakin & Clemants, *Eclipta prostrata* (L.) L., *Eragrostis virescens* J.Presl, *Lindernia dubia* (L.) Pennell, *Mollugo verticillata* L., *Panicum dichotomiflorum* Michx., *Persicaria pensylvanica* (L.) M.Gómez, *Setaria parviflora* (Poir.) Kerguélen, *Solanum chenopodioides* Lam., etc. Native species that are found in the company of *A. tuberculatus* are, among others, *Cyperus fuscus* L., *C. michelianus* (L.) Link, *Eragrostis pilosa* (L.) P.Beauv. and *Glinus lotoides* L.

Discussion

During recent fieldwork, the massive presence of the North American weed *Amaranthus tuberculatus* was noted on the banks of the Tagus River in Portugal. Tens of thousands of individuals of this dioecious species, both male and seed-bearing female plants (Fig. 2b), were observed on the exposed sand and mud banks, over a distance of approximately 60 kilometers. The plants were almost exclusively observed in the immediate vicinity of the river. Only near Azinhaga, where the species is also abundant along the tributary Almonda, was it also found along field roads, at a distance of about half a kilometer from the river. Although much of the valley is intensively farmed (a lot being devoted to maize) and many of these crops are severely affected by weeds, including several amaranth species, *A. tuberculatus* was not observed in any fields. This is remarkable because the species is known to have been introduced into Europe as a contaminant in American cereals or oilseeds. Such grain or oil seed aliens usually end up in fields *via* animal manure (i.e. undigested seeds or fruits; compare with Pleasant and Schlather 1994 or Larney and Blackshaw 2003). The presence of quite a few weeds in the local corn fields can probably be explained in this way, but this does not apply to *A. tuberculatus*.

The species' introduction pathway thus can only be speculated upon. There are several grain transhipment locations along the Tagus, including a Cargill mill, where cereals and oilseeds from America are unloaded, but these are located far downstream from the sites of *A. tuberculatus*. In the vicinity of these factories, grain aliens were found during our recent fieldwork, such as *Amaranthus palmeri*, another quite invasive dioecious amaranth not previously recorded in Portugal, as well as *Persicaria pensylvanica*. It is rather unlikely that the presence of *A. tuberculatus* further upstream is related to this industry. It is nevertheless interesting that the species, which is a fairly typical American soybean alien, was found along with other soybean aliens on the banks of the Tagus, such as the previously mentioned *Persicaria pensylvanica* but also *Physalis angulata* L., another American weed that had not previously been found in Portugal (Verloove and Alves, in prep.). Interestingly, *A. tuberculatus* was once cultivated in the Coimbra Botanical Garden (GBIF), at least between 1938 and 1953. It is unclear whether this is still the case, but probably not (comm. J. Domingues de Almeida, January 2025). However, given the distance between Coimbra and the Tagus River, about 150 km, and the absence of the species in the area in between, it is probably unlikely that the origin of the plants should be sought there. Two further possible vectors of introduction are probably the most plausible. The species could have been introduced by migratory birds from (relatively) nearby regions where the species is naturalized, most likely Italy. The recent appearance of the species in Croatia is also explained in this way (Rimac et al. 2020). Alternatively, international fishing tourism along the river, including the provision of fish food, could also be a potential source of introduction. The Po and Tagus Rivers, known for their (invasive) catfish populations, attract specialized catfish anglers who may inadvertently introduce seeds through their equipment (compare with Nagy et al. 2025). However, how exactly the species arrived on the banks of the Tagus will remain a mystery.

Regardless, if *A. tuberculatus* reaches and becomes established in the agricultural fields along the Tagus River, it could become a troublesome weed. The species is a very strong, fast-growing and therefore competitive weed (despite its annual life form, it can easily reach 3 m in height) (Mosyakin and Robertson 2003). Furthermore, the species is resistant to several herbicides (Schultz et al. 2015, Shergill et al. 2018, Roth et al. 2023). It is unclear what impact the species currently has in the invaded areas. As mentioned before, it is primarily a potentially aggressive weed in agricultural areas, while the negative impact of the species in (semi-)natural environments, such as riparian habitats, remains unclear. Given the unusually large populations in which the species occurs, a logical consequence of the massive seed production and the vigor

of the species, it occupies large areas. It outcompetes much less robust native species from periodically exposed shores with stable, mesotrophic sediments with pioneer or ephemeral vegetation, such as *Cyperus michelianus*, *Glinus lotoides*, etc. Additionally, a large proportion of other species growing on the sand and mud bars of the Tagus River are also exotic, posing a threat to native flora and vegetation.

Finally, questions can be raised regarding such a massive presence of *A. tuberculatus* along the Tagus River. Perhaps the species has been present there for a long time but remained unnoticed, as a result of confusion with other amaranths? Or is it perhaps a recent, rapidly expanding introduction? To answer these questions, online biodiversity databases such as GBIF, iNaturalist or observation.org were consulted, specifically for the region where *A. tuberculatus* was found. Although the valley is visited regularly by naturalists, no previous observations of the species have been detected, neither under the name *A. tuberculatus* nor under other amaranth species names (several other amaranths have nevertheless been documented with photographs in recent years from the banks of the Tagus River). Either the species has not been noticed until now (despite its size and the fact that it is clearly different from the other amaranths present on the banks; Fig. 2), which therefore seems rather unlikely, or it is indeed a relatively recently introduced, very rapidly spreading neophyte. Considering how the species has spread over large parts of northern Italy in just a few decades, especially along river systems, the species' future expansion in Portugal seems almost inevitable.

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