DRAFT WRITTEN FINDINGS OF THE WASHINGTON STATE NOXIOUS WEED CONTROL BOARD

SCIENTIFIC NAME: *Amaranthus tuberculatus*

SYNONYMS: *Amaranthus rudis, Amaranthus tuberculatus var. rudis, Amaranthus tuberculatus var. prostrates, Amaranthus tuberculatus var. subnudus, Amaranthus latissimus, Amaranthus ambigens, Amaranthus cannabinus, Acnida altissima, Acnida cannabina, Acnida concatenata, Acnida subnuda, Acnida tamariscina, Acnida tuberculata, Montelia tamariscina* (USDA)

COMMON NAMES: Waterhemp, rough-fruit waterhemp, roughfruited amaranth, tall waterhemp, common waterhemp

FAMILY: Amaranth family, Amaranthaceae

LEGAL STATUS: Considered for Class A

DESCRIPTION AND VARIATION

OVERALL HABIT:

Amaranthus tuberculatus is an herbaceous, summer annual broadleaf weed, it completes its lifecycle in a single growing season, typically during the warmer months (Soltani *et al*., 2023; Gage *et al.*, 2021). It exhibits high phenotypic plasticity, varying widely in growth habit and morphology depending on environmental factors and plant competition (Heneghan & Johnson, 2017; Korres & Norsworthy, 2017).

A young plant. Bruce Ackley, Ohio State University.

STEMS:

Amaranthus tuberculatus stems are generally erect and can grow quite tall, ranging from 0.2 to 2 m, and sometimes up to 3 m in height (Costea *et al.,* 2005; Tabašević *et al.,* 2020). The stems are usually smooth, typically branched, and often have a reddish hue (Tabašević *et al.,* 2020; Costea *et al.,* 2005). Stem morphology, including branching patterns and color (from green to red-ish), can be extremely variable depending on environmental conditions and any injury the plant sustains (Costea *et al.,* 2005).

LEAVES:

The leaves of *Amaranthus tuberculatus* are arranged alternately along the stem and are attached by a leaf stalk (petioled). They are generally smooth on the surface and do not have serrations or lobes along the edges, though may be slightly wavy. (Tabašević *et al.,* 2020). Leaf shape is variable, ranging from ovate (egg-shaped) to rhombic-oblong (diamond-shaped to elongated) to lanceolate (lance-shaped or spearhead-shaped), typically 2–10 centimeters long and 1–3 cm wide (Costea *et al.,* 2005; Tabašević *et al.,* 2020). Upper leaves are usually smaller and narrower than lower leaves (Costea *et al.,* 2005).

Young plants and leaves. Bruce Ackley, Ohio State University

FLOWERS:

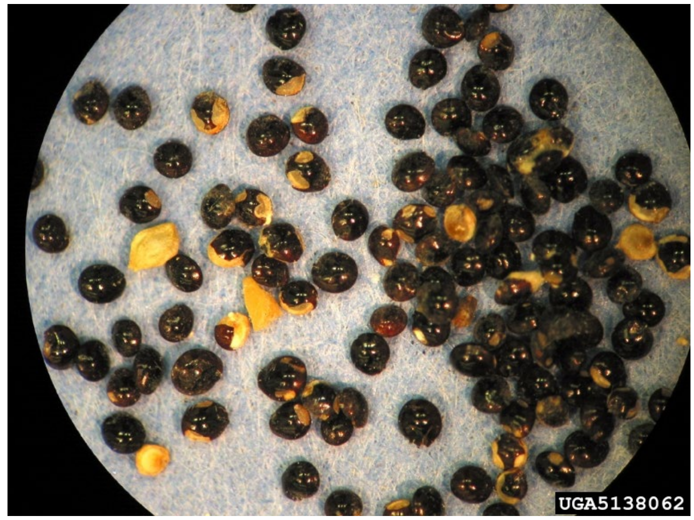
Amaranthus tuberculatus are dioecious (Soltani *et al.,* 2023) and wind pollinated (Liu *et al.,* 2012; Waselkov *et al.,* 2020). The inconspicuous flowers are small and grouped in clusters in the leaf axils, where the leaf meets the stem, and more prominently in dense, cylindrical, spike-like or panicle-like, branched, flower clusters at the ends of stems (Costea *et al.,* 2005; Tabašević *et al.,* 2020). These inflorescences are often reddish or green and can be 10–20 cm long (Tabašević *et al.,* 2020; Costea *et al.,* 2005).

Male flowers have five unequal tepals (when sepals and petals when they are indistinguishable). The outer three tepals are about 3 millimeters long and pointed, while the inner two are shorter and may be blunt or notched. Male flowers have five stamens (Costea *et al.,* 2005).


Flowers. Zoya Akulova

Female flowers have one or two tepals (often rudimentary or one narrow-lanceolate tepal about 2 mm long). They lack a style (the stalk connecting stigma to ovary) and have three prominent, long, feathery stigmas (Tabašević *et al.,* 2020; Costea *et al.,* 2005). Bracts at the base of flowers are 1.5–2.5 mm long (Costea *et al.,* 2005).

FRUITS/SEEDS:



Seeds under dissecting microscope.
Lynn Sosnoskie, University of Georgia

Amaranthus tuberculatus is a small-seeded weed (Soltani *et al.,* 2023). The seed grows in a small, single-seeded, egg-shaped utricle (a type of dry, one-seeded fruit) about 1.5 mm long, though the size varies by plant and environment (Tabašević *et al.,* 2020; Costea *et al.,* 2005). The fruit surface is wrinkled or rough and often reddish. It typically opens by a horizontal lid-like split around its circumference to release the seed, though individuals may have fruit that does not open (Costea *et al.,* 2005; Pratt & Clark, 2001). Seeds are about 1 mm long, elliptic to egg-shaped, dark reddish-brown to black, and shiny with a prominent, conical seed scar (Tabašević *et al.,* 2020; Costea *et al.,* 2005). A single female plant can produce between 35,000 to over 1 million seeds, with some reports of up to 4.8 million seeds under non-competitive conditions (Costea *et al.,* 2005; Heneghan & Johnson, 2017; Gage *et al.,* 2021).

ROOTS:

Amaranthus tuberculatus has a taproot system (Gage *et al.,* 2021). The taproot can extend over 63 cm deep into the soil, and several secondary roots may reach over 1.8 m beyond the plant stem (Gage *et al.,* 2021). This deep taproot allows plants to utilize water resources effectively even from drier locations while the branching lateral roots enable plants to explore moisture resources (Korres, 2017).

SIMILAR SPECIES:

There are several *Amaranthus* species that occur in Washington (Burke Herbarium), many of which are difficult for the general public to distinguish.

Amaranthus palmeri (Palmer amaranth leaves commonly exhibit a distinctive V-shaped variegation and prominent venation, differentiating it from other species (Steckel, 2007). Leaves on *A. tuberculatus* are often narrower than those on *A. retroflexus* (common ragweed), *A. powellii*, and *A. hybridus* (Vyn *et al.,* 2006; Costea *et al.,* 2005). The pattern and amount of pubescence on stems and leaves of Amaranthus species may be able to help identify individuals, but this method of identification has not been formalized in the literature.

HABITAT:

Amaranthus tuberculatus has a natural affinity for riparian habitats such as floodplains, lakeshores, marshes, riverbanks and along streams, ditches, and ponds, primarily owing to high soil humidity, ample moisture availability and suitable substrate/soil composition for seeds germination (USDA/NRCS, 2004). It thrives in disturbed habitats, including roadsides, railroads, and cultivated fields (Tabašević *et al.,* 2020; Costea *et al.,* 2005). It prefers well-drained, nutrient-rich soils but can tolerate a broad range of soil types and textures, with a soil pH range of 4.5 to 8 (Gage *et al.,* 2021; Costea *et al.,* 2005). It can tolerate temporary flooding but has little tolerance for salinity (Gage *et al.,* 2021; Costea *et al.,* 2005).

Growing on a roadside. Zoya Akulova.

BIOLOGY

GROWTH AND DEVELOPMENT:

Amaranthus tuberculatus displays a rapid growth rate under ideal conditions. In optimal conditions with no competition for resources *A. tuberculatus* grew as much as 5 cm daily. *A. tuberculatus* emerged after most crop seedling species have grown, making weed management with post-emergence applied herbicides a challenge (Tranel *et al.,* 2020). It has a prolonged and relatively staggered (Wachelkov *et al.* 2020) emergence pattern, allowing for new weed plants to come up for extended durations and across entire cropping period depending on precipitation pattern. Seedling plants can emerge up to mid or late season or as delayed emergence (Costea *et al.,* 2005). Optimal temperature for *A. tuberculatus* emergence is 33° to 35°C while it displays an upper growth temperature limit as observed under temperatures exceeding 40° C. The lower growth limit varied with region of origin among population pairs and between generations among accessions. The effect of other factors for both upper and lower limits can vary with genetic make-up, site or location and various agronomical/crop management measures including weed management programs implemented (Wachelkov *et al.,* 2020). It has a C4 photosynthetic pathway, making it highly efficient in hot, sunny conditions (Butts *et al.,* 2018; Costea *et al.,* 2005). Flowering is initiated by day length, typically as the days get shorter (Costea *et al.,* 2005; Heneghan & Johnson, 2017). Seeds can become mature and viable as early as 7 to 11 days after pollination (DAP) (Bell & Tranel, 2010). Freshly shed seeds often exhibit dormancy, which can be overcome by cold stratification (a period of cold, moist conditions) (Bell & Tranel, 2010; Leon & Owen, 2006).

REPRODUCTION:


Male and female plants. Christophe Bornand

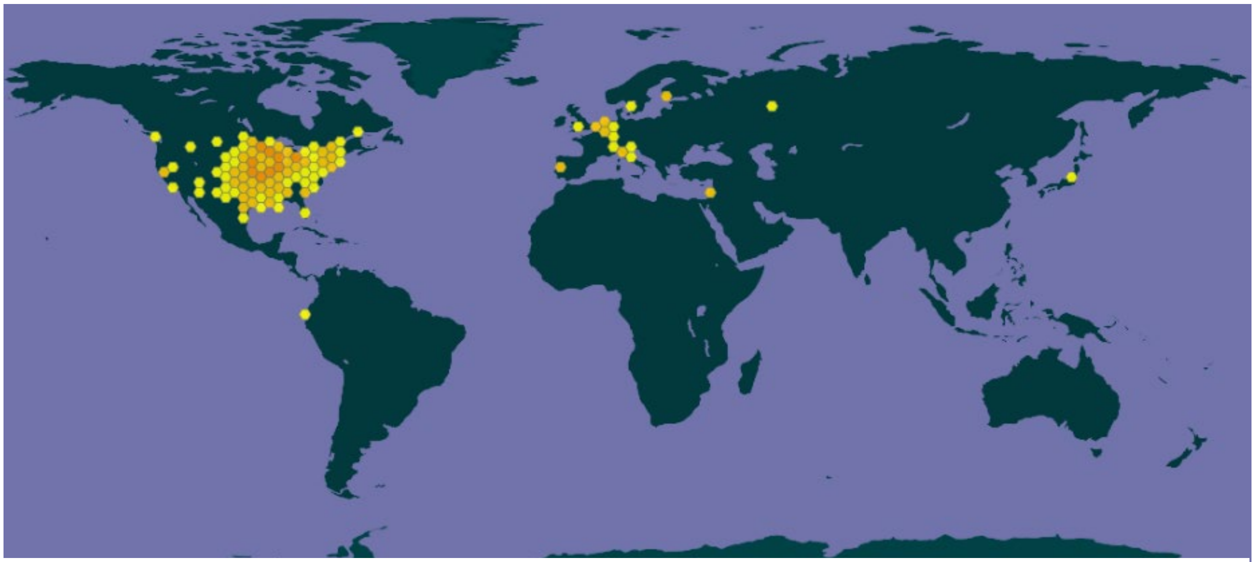
A. tuberculatus reproduces solely by seed (Gage *et al.,* 2021; Costea *et al.,* 2005). Being dioecious (separate male and female plants), it is an obligate outcrosser, meaning pollen from a male plant must fertilize a female plant for seed set (Hamberg *et al.,* 2023; Montgomery *et al.,* 2020; Costea *et al.,* 2005). This mandatory outcrossing ensures high genetic diversity and facilitates rapid adaptation, including the spread of herbicide resistance (Tranel *et al.,* 2020; Gage *et al.,* 2021). Pollination is primarily by wind (anemophilous) (Liu *et al.,* 2012; Costea *et al.,* 2005). A. tuberculatus pollen can remain viable for up to 120 hours (5 days) under certain conditions, and while most pollen fertilizes plants within 50 m, long-distance dispersal up to 800 m has been observed (Liu *et al.,* 2012).

Seed production is prolific; a single female plant can produce over 1 million seeds under non-competitive conditions, and up to 300,000–500,000 seeds even when competing with crops like corn or soybean (Gage *et al.,* 2021; Steckel, 2007; Schwartz *et al.,* 2016). Up to 80% of seeds produced are viable (Gage *et al.,* 2021). Seeds can remain viable in the soil seedbank for many years, with reports of 1–3% viability after 17 years of burial (Soltani *et al.,* 2023; Gage *et al.,* 2021). Seed dispersal occurs via water, farm machinery, contaminated manure/compost, birds, and other animals, and to some extent by wind (Schwartz *et al.,* 2016; Gage *et al.,* 2021). Waterfowl have been documented to disperse pigweed seeds, including *A. tuberculatus* (Gage *et al.,* 2021). Seeds are small and generally gravity-dispersed initially but can be moved further by the listed vectors (Costea *et al.,* 2005; Schwartz *et al.,* 2016). High seed retention (over 95%) on the plant at soybean maturity means many seeds pass through combines during harvest (Schwartz *et al.,* 2016).

GEOGRAPHIC DISTRIBUTION

NATIVE DISTRIBUTION

Amaranthus tuberculatus is native to North America, specifically the Midwestern United States (Waselkov *et al.,* 2020; Gage *et al.,* 2021). The *var. rudis* form was historically found west of the Mississippi River, from Nebraska to Texas, while the *var. tuberculatus* form was east of the Mississippi, from Indiana to Ohio, with a zone of overlap in Iowa, Illinois, and Missouri (Pratt & Clark, 2001; Costea *et al., 2005*).



Worldwide distribution. Global Biodiversity Information Facility

NON-NATIVE DISTRIBUTION

Amaranthus tuberculatus has established itself in much of the United States, and has been reported in Mexico and since at least 2002 in Ontario, Canada (Vyn *et al.,* 2006; Soltani *et al.,* 2023). It has also been introduced into Europe, Israel, (Tabašević *et al.,* 2020) and Australia (Steckel, 2007), often initially found near ports or in disturbed riparian areas, likely introduced as a contaminant in grain shipments (Tabašević *et al.,* 2020; Rimac *et al.,* 2020; Bürki *et al.,* 2001; Roth *et al.,* 2023). *A. tuberculatus* has naturalized across a handful European nations. Since initial reports in 1957, its expanded distribution areas include certain parts Italy plus also Belgium including few Czech Republic districts particularly around coast regions extending slightly into those border adjacent with other EU members (Costea *et al.,* 2005).

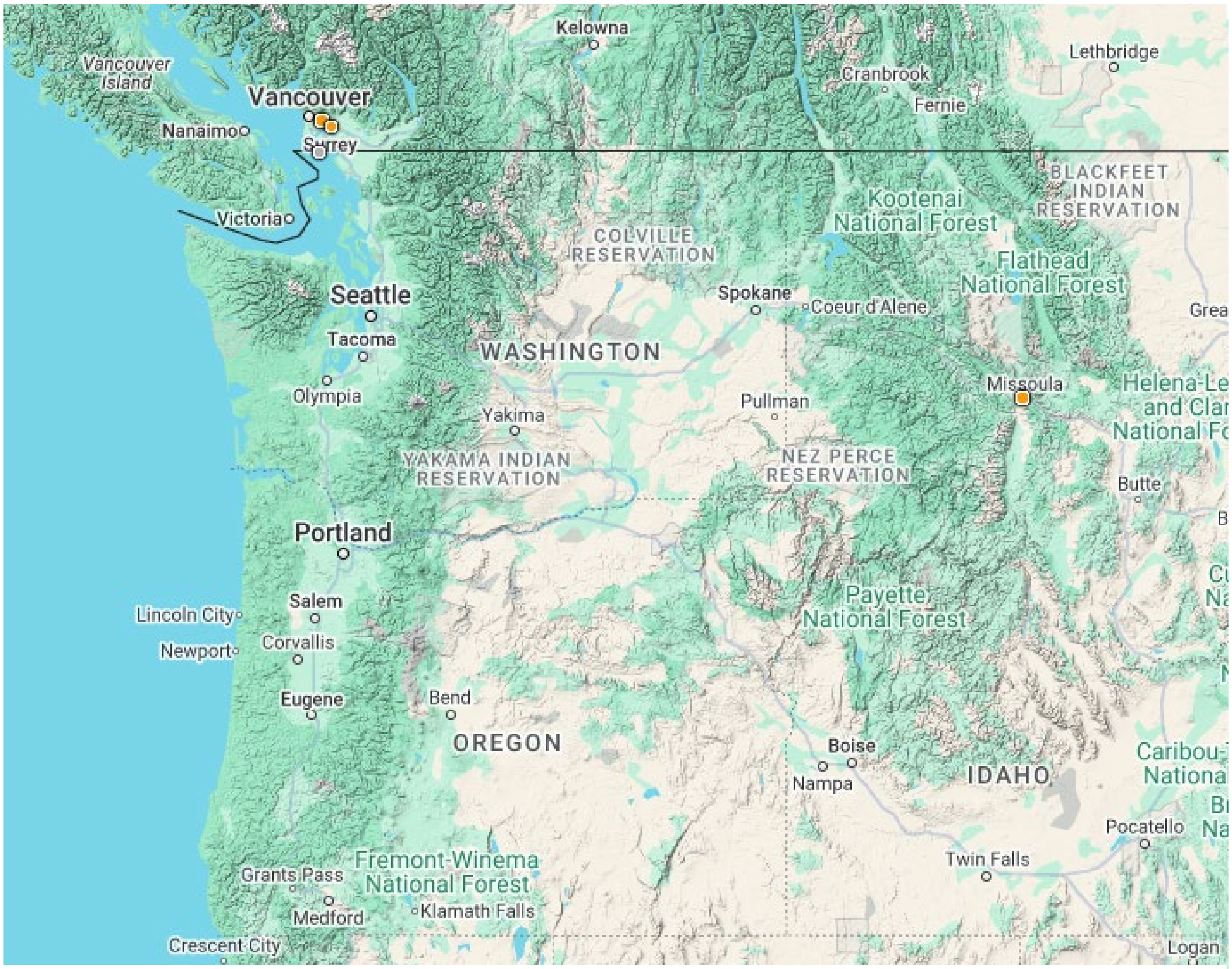
HISTORY:

Since the 1950s, and especially since the 1980s with changes in tillage and herbicide practices, *Amaranthus tuberculatus* has expanded its range and become a problematic weed in agricultural fields across much of the Midwest and into the southern and eastern US. This agricultural adaptation could have occurred within generations due to A. tuberculatus' highly adaptive traits (Gage *et al.,* 2021; Steckel, 2007; Vyn *et al.,* 2006; Costea *et al.,* 2005).

WASHINGTON:

There are no records of *Amaranthus tuberculatus* in Washington in the Burke Herbarium, Consortium of Pacific Northwest Herbaria, or on iNaturalist.

The USDA plants database lists *A. tuberculatus* as native in Washington.



PNW Records. Consortium of Pacific Northwest Herbaria.

NEARBY TO WASHINGTON:

OREGON:

There are no records of *Amaranthus tuberculatus* in Oregon in the Consortium of Pacific Northwest Herbaria, or on iNaturalist.

The USDA plants database does not list *A. tuberculatus* as native in Oregon.

IDAHO:

There are no records of *Amaranthus tuberculatus* in Idaho in the Consortium of Pacific Northwest Herbaria, or on iNaturalist. There is a record in the Consortium of Pacific Northwest Herbaria near Missoula, Montana.

The USDA plants database lists *A. tuberculatus* as native in Idaho, but not in Montana.

BRITISH COLUMBIA:

The Consortium of Pacific Northwest Herbaria has 6 records of *Amaranthus tuberculatus* in British Columbia, all from the Vancouver area and between the years of 1988 and 2003.

CALIFORNIA

Calflora has 14 records of *Amaranthus tuberculatus*, primarily in the central valley.

The USDA plants database lists *A. tuberculatus* as native in California, but not in Oregon, Nevada, Utah, or Arizona.

Records in California. Calflora.

LISTINGS:

In the United States, only Ohio and Pennsylvania have *Amaranthus tuberculatus* on their noxious weed lists (EDDMapS). However, it is considered naturalized in China, invasive in Italy and Ontario, and 40 US states consider it invasive in agricultural fields (Iamonico, 2015).

ECONOMIC AND ECOLOGICAL IMPORTANCE

DETRIMENTAL:

Amaranthus tuberculatus is one of the most problematic weeds in major row crops like corn, soybean, and carrots in the US (Soltani *et al.,* 2023; Butts *et al.,* 2018). It causes significant yield losses due to competition for light, water, and nutrients. Soybean yield losses can reach 43–73% (Soltani *et al.,* 2023; Gage *et al.,* 2021), and corn yield losses can range from 11% to 74%, depending on *A. tuberculatus* density and soil moisture (Vyn *et al.,* 2006; Gage *et al.,* 2021). In Illinois alone, it accounts for about 10% of weed control costs (Waselkov & Olsen, 2014). The evolution of multiple herbicide resistance significantly increases management costs and limits effective control options (Tranel *et al.,* 2011; Hamberg *et al.,* 2023). Late-season escapes, even if they don't significantly reduce current crop yield, contribute substantially to the soil seedbank, increasing future weed pressure and management costs (Werner *et al.,* 2020; Soltani *et al.,* 2023).

As an invasive agricultural weed, *A. tuberculatus* can outcompete native plant species in disturbed areas adjacent to farmlands or in riparian zones it invades (Tabašević *et al.,* 2020; Rimac *et al.,* 2020). Its high seed production and persistent seedbank allow it to form dense stands that can alter local plant community structure (Schwartz *et al.,* 2016). Under certain conditions (e.g., drought stress), *Amaranthus* species can accumulate nitrates to levels toxic to livestock if ingested (Steckel, 2007). *A. tuberculatus* also produces allelopathic compounds (biochemicals that inhibit the growth of other plants), which may interfere with the germination and growth of neighboring plants, including crops (Gage *et al.,* 2021). The spread of herbicide resistance genes through pollen flow to other compatible *Amaranthus* species, if possible, could also be an ecological concern (Trucco *et al.,* 2009).

Growing amongst corn. Duilio Iamonico.

BENEFICIAL:

Historically, Native Americans used various *Amaranthus* species, including *Amaranthus tuberculatus*, for food. The seeds were toasted and milled, and the leaves were sometimes boiled or baked (Steckel, 2007). While other *Amaranthus* species are cultivated as grain (pseudocereals) or vegetables, *A. tuberculatus* itself is not currently recognized for such direct economic benefits, primarily being viewed as a detrimental weed in modern agriculture. Its genetic diversity, however, particularly regarding herbicide resistance, could theoretically be a source of traits for other *Amaranthus* crops, though this is highly speculative and complex (Trucco *et al.,* 2009).

Specific beneficial ecological impacts of *A. tuberculatus* are not widely documented in the provided literature, which focuses on its weedy nature. However, like many plants, it would contribute to primary production and potentially serve as a food source for some specialized insects or granivorous birds (seed-eating birds) (Gage *et al.,* 2021). Its historical presence in riparian ecosystems suggests it played a role in those native plant communities before its agricultural expansion (Waselkov & Olsen, 2014). Generally, weeds can provide cover and food for wildlife, hold soil, and provide mulch, though it is unknown how much *A. tuberculatus* can contribute to any of these goals.

CONTROL

MECHANICAL:

Hand-weeding can be effective, especially for removing late-season escapes to prevent seed production (Nguyen & Liebman, 2022). However, this is labor-intensive and impractical for large infestations, especially due to the long taproot and branching lateral roots (Steckel 2007).

A dense stand. Liam O'Brien.

Tillage (such as plowing or cultivation) can control *A. tuberculatus* seedlings. Primary tillage can control emerged seedlings, and strategic moldboard plowing can bury seeds deeper than their emergence depth (1.4 inches or 3.5 cm), thus preventing germination (Gage *et al.,* 2021; Leon & Owen, 2006). However, tillage can also bring buried seeds to the surface. Cultivation is effective only on small seedlings; mature plants may re-root (Gage *et al.,* 2021). Methods like chaff lining or using impact mills (seed destructors) are being researched (Gage *et al.,* 2021). Mowing alone is not a good option as plants can re-branch and still produce seed (Gage *et al.,* 2021).

CULTURAL:

Reducing disturbance, planting with known seed stocks and clean tools, boots, and vehicles between sites can all help stop new infestations. Harvesting from known infested sites and using strategic harvesting methods can also reduce spread (Gage *et al.,* 2021).

Cultural practices that enhance crop competitiveness are vital (Gage *et al.,* 2021). Diversifying crop rotations disrupts weed cycles and allows for a broader range of management tactics, including different herbicide options (Soltani *et al.,* 2023; Gage *et al.,* 2021). For instance, including small grains or perennial forages can suppress *Amaranthus tuberculatus* (Nguyen & Liebman, 2022). Planting cover crops can suppress *A. tuberculatus* emergence and growth through physical impediment, light competition, and possibly allelopathy (Soltani *et al.,* 2023; Yadav *et al.,* 2023; Gage *et al.,* 2021). Narrow row spacing and increased seeding rates can promote faster crop canopy closure, which shades out emerging *A. tuberculatus* seedlings (Yadav *et al.,* 2023; Gage *et al.,* 2021; Leon & Owen, 2006). Ensuring

A plant that has not begun flowering yet. John D. Byrd, Mississippi State University.

a weed-free seedbed at planting through effective burndown herbicides or tillage is crucial (Gage *et al.,* 2021). Cleaning farm equipment to prevent seed spread between fields, harvesting infested fields last, and using certified crop seed are important preventative measures (Gage *et al.,* 2021).

BIOLOGICAL:

Biological control is currently difficult to implement as there are no approved biological control agents specifically for *Amaranthus tuberculatus* (Gage *et al.,* 2021). Some native insects, like the amaranth flea beetle (*Disonycha glabrata*), and generalist seed predators like ground beetles and crickets, consume *A. tuberculatus* foliage or seeds, respectively. Maintaining residue or cover crops can enhance these seed predators (Gage *et al.,* 2021). Certain fungal pathogens, such as *Microsphaeropsis amaranthi* have shown promise as mycoherbicides (bio-herbicides based on fungi) for controlling *Amaranthus* species, including *A. tuberculatus*, but their efficacy can be limited by environmental conditions (e.g., humidity) and compatibility with chemical herbicides (Bürki *et al.,* 2001; Gage *et al.,* 2021). Other fungi like *Alternaria alternata* and *Trematophoma lignicola* have also been investigated in Europe (Bürki *et al.,* 2001).

CHEMICAL:

Chemical control has become increasingly challenging due to widespread herbicide resistance in *Amaranthus tuberculatus* (Hamberg *et al.,* 2023; Tranel *et al.,* 2011). *A. tuberculatus* has evolved resistance to at least seven herbicide sites of action, including ALS inhibitors (e.g., imazethapyr), PSII inhibitors (e.g., atrazine), PPO inhibitors (e.g., lactofen, fomesafen), EPSPS inhibitors (glyphosate), HPPD inhibitors (e.g., mesotrione), synthetic auxins (2,4-D, dicamba), and VLCFAE inhibitors (Soltani *et al.,* 2023; Gage *et al.,* 2021; 2023; Tranel *et al.,* 2020). Multiple herbicide resistance (resistance to herbicides from two or more sites of action in the same population or plant) is common (Hamberg *et al.,* 2023; Soltani *et al.,* 2023).

A flowering plant. Bruce Ackley, Ohio State University.

Effective chemical control requires knowing the resistance profile of the local population (Gage *et al.,* 2021). Programs should use pre-emergence herbicides with multiple effective sites of action, followed by timely post-emergence applications if needed, also with multiple effective sites of action or different sites of action than used pre-emergence (Yadav *et al.,* 2023; Gage *et al.,* 2021). Post-emergence applications are most effective on small plants (less than 4 inches tall) (Gage *et al.,* 2021). Due to widespread ALS resistance, these herbicides are generally not reliable (Hamberg *et al.,* 2023). Glyphosate resistance is also very common (Hamberg *et al.,* 2023). PPO inhibitors (e.g., fomesafen, lactofen) and HPPD inhibitors (e.g., mesotrione) can be effective if resistance is not present, often in combination with atrazine in corn (Gage *et al.,* 2021; Vyn *et al.,* 2006; Yadav *et al.,* 2023). Glufosinate is effective in glufosinate-resistant crops if applied to small plants with good coverage (Gage *et al.,* 2021). Auxin herbicides like 2,4-D and dicamba are options in tolerant crop systems, but resistance to these is also emerging (Bernards *et al.,* 2012; Gage *et al.,* 2021).

RATIONALE FOR LISTING

Amaranthus tuberculatus is a highly competitive summer annual, which is difficult to control. It has high seed production, is fast growing, easily evolves herbicide resistances, and is very drought tolerant. These traits make it an aggressive agricultural weed, especially in row and annual crops (Korres *et al.* 2018; Tranel *et al.* 2011). While it is native to the United States, is native range is most likely in the Midwest, around the great lakes and great plains (Waselkov *et al.,* 2020; Gage *et al.,* 2021).

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