FRINGED AMARANTH

Amaranthus fimbriatus (Torr.) Benth. Ex S. Watson

Amaranthaceae- Amaranth Family

Casey Hensen and Ashlee Wolf |2023

ORGANIZATION

NOMENCLATURE

Fringed amaranth (*Amaranthus fimbriatus* (Torr.) Benth. ex S. Watson) is in the Amaranthaceae, or amaranth family (FNA 2023a). Its closest phylogenetic relative is *A. urceolatus*, a South American species (Waselkov and Olsen 2018).

NRCS Plant Code.

AMFI (USDA NRCS 2023).

Synonyms.

Amblogyna fimbriata (Torr.) A.Gray, Sarratia berlanderi var. fimbriata (Torr.) W.H. Emory, Amaranthus fimbriatus var. denticulatus (Torr.) Uline & W.L. Bray, Amaranthus venulosus S.Watson, Sarratia berlandieri var. denticulata Torr. (POWO 2023).

Common Names.

Fringed amaranth, fringed pigweed, pigweed, and blite (FNA 2023a, SEINet 2023a). Common names in Spanish include *bledo* and *quelitillo* (Felger et al. 2014).

Subtaxa.

Two varieties are recognized by the Flora of North America: *Amaranthus fimbriatus* var. *fimbriatus* and *Amaranthus fimbriatus* var. *denticulatus* (= *A. venulosus* S. Watson) (FNA 2023a).

Chromosome Number.

The chromosome number for fringed amaranth is 2n=34 (Costea 2012, FNA 2023a).

Hybridization.

Fringed amaranth has not been documented to hybridize with related species. However, some species of *Amaranthus* have occasionally formed interspecific hybrids. The frequency of hybridization in the genus is thought to be overestimated, and some putative hybrids are actually nonhybrid forms of morphologically variable species (FNA 2023b).

DESCRIPTION

Fringed amaranth is a glabrous, annual forb that is often reddish in coloration. It can reach heights of up to 70 cm, with stems erect and sparingly branched. Its leaves are alternate and based on short petioles, blades linear to lanceolate with margins entire. The inflorescence is a spike with monecious green and white flowers, which can occasionally be pink-tinged. The spike is unbranched, slender, and leafless. The female (pistillate) and male (staminate) flowers both have 5 tepals (female tepals clawed, males tepal apices obtuse), while the bracts of the pistillate flower are ovate and shorter than its tepals. In staminate flowers, the bract apex is obtuse. The fruits (utricles) are subglobose to ovate (1-2 mm) with seeds that are black to dark reddish brown, shiny, and smooth (FNA 2023a, SEINet 2023a).

It may be confused with *A. torreyi*, however, *A. torreyi* has shorter, wider leaves and the pistillate tepals have entire margins as opposed to the fimbriate or denticulate margins of *A. fimbriatus*. (SEINet 2023a).

Figure 1: A fringed amaranth individual. Photo: BLM SOS NV052

Figure 2: The inflorescence of fringed amaranth. Photo: Sue Carnahan

Varieties or Subspecies.

Var. *fimbriatus* can be distinguished by its tepals which are fimbriate at the apex. This variety is found primarily in Arizona (and parts of California), including Maricopa, Coconino, and Pinal counties between 1,700-3,800 feet (518-1150 m) in elevation. Its habitat is dry, rocky slopes, washes, and riparian scrub (SEINet 2023b).

Var. *denticulatus*, has denticulate or crenulate tepals and can be found in Arizona, northern Mexico, and Baja California between 900-1,400 feet (274-537 m) in elevation. It grows on dry mud, alkaline substrates, and in costal scrub areas (SEINet 2023c).

DISTRIBUTION AND HABITAT

Fringed amaranth is a common native forb in the Mojave and Sonoran desert ecoregions in California, Nevada, Arizona, and Mexico (SEINet 2023a). Records become increasingly sparse in neighboring ecoregions such as the northern Central Basin and Range, Southern California Oak Woodlands, Arizona/New Mexico Plateau, and the Chihuahuan deserts.

Habitat and Plant Associations.

Fringed amaranth grows in sandy and gravelly washes, bajadas, rocky hillsides, alluvial plains and valleys. Its primary vegetation communities are sparse creosote desert scrub, Joshua tree woodlands, and desert washes (SWDF 2017, BLM SOS 2022).

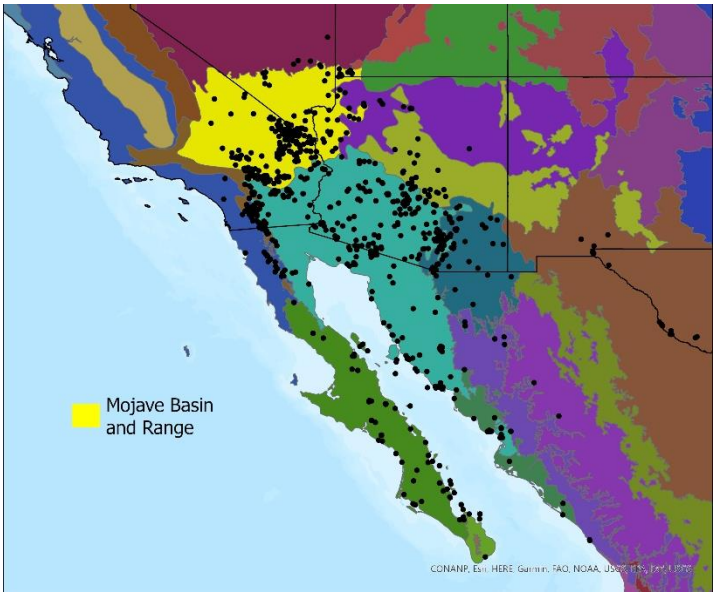

Figure 3: Distribution of fringed amaranth based on georeferenced herbarium specimens and verified observations (black circles, SEINet 2022) with EPA Level III Ecoregions (US EPA 2015). The Mojave Basin and Range ecoregion is shown in yellow.

NatureServe does not recognize any alliance or association records for fringed amaranth. As a species, NatureServe categorizes fringed amaranth as globally secure (G5). However, it is ranked as vulnerable (S3) in Nevada and critically imperiled (S1) in Utah. There are no status ranks for surrounding states nor descriptions of threats (Kartesz 1994).

The listed associated species from Seeds of Success collections in the Mojave Desert for fringed amaranth are: creosote bush (*Larrea tridentata*), Joshua tree (*Yucca brevifolia*), six-weeks grama (*Bouteloua barbata*), needle grama (*Bouteloua aristidoides*), catclaw acacia (*Acacia greggii*), littleleaf ratany (*Krameria erecta*), Acton's brittlebrush (*Encelia actonii*), common reed (*Phragmites australis*), Mojave rabbitbrush (*Ericameria paniculata*), desert trumpet (*Eriogonum inflatum*), manybristle chinchweed (*Pectis papposa*), spiny mendora (*Menodora spinescens*), nineawn pappusgrass (*Enneapogon desvauxii*), and burrobush (*Ambrosia dumosa*) (BLM SOS 2022).

Figure 4: Fringed amaranth in a Joshua tree woodland habitat in Nevada. Photo: BLM SOS NV052

Figure 5: Fringed amaranth habitat on the margins of an ephemeral wash in Nevada Photo: BLM SOS NV052

Climate.

The Mojave Desert is characterized by low annual precipitation (5-25 cm or 2-10 inches in valley areas), with most rainfall occurring in the winter and a smaller amount during summer thunderstorms (Randall et al. 2010). Heterogenous climate patterns across the region are influenced by large-scale patterns and regional topography and are important drivers of local adaptation and intraspecific variation (Shryock et al. 2018, Baughman et al. 2019) and phenological events (Beatley 1974). Specifically, the reproductive phenology of many desert plant species is highly responsive to pulses in rainfall over short time scales (Bowers and Dimmitt 1994, Zachmann et al. 2021).

Climate information is derived from the climate-based provisional seed transfer zones (PSZs) where fringed amaranth occurs (Shryock et al. 2018; Table 1). According to herbarium specimen locations (SEINET 2022), fringed amaranth has been collected from all PSZs in the Mojave Desert ecoregion, except Zones 22 and 28. Collections are most abundant from Zones 25 and 29 and least abundant from Zone 24 (Table 1). The average annual precipitation in the PSZs where fringed amaranth occurs in the Mojave Desert ecoregion is 16.7 cm (6.6 inches), with an average of 5.2 cm (2.0 inches) falling in the summer and an average of 11.5 cm (4.5 inches) falling in the winter. Note, herbarium specimen locations may not represent the full distribution and abundance of fringed amaranth due to sampling biases and ephemerality of this desert annual.

Table 1: Climate of the provisional seed zones (PSZ) where fringed amaranth occurs within the Mojave Desert ecoregion (Shryock et al. 2018).# = the number of herbarium or verified observations of fringed amaranth within the PSZ (SEINet 2022); MAP=mean annual precipitation; SP=summer precipitation, or the mean precipitation that falls in the summer (May-October); WP= winter precipitation, or the mean precipitation that falls in the winter (November-April); MAT=monthly average temperature; Range= Average of the monthly temperature ranges (monthly maximum minus monthly minimum).

PSZ	#	MAP (cm)	SP (cm)	WP (cm)	MAT (C)	Range (C)
25	95	16.5	6.2	10.3	18.9	34.6
29	83	25.5	4.2	21.4	13.8	31.7
23	69	15.8	5.4	10.4	16.1	35.9
20	61	25.5	10.5	14.9	15.3	34.5
26	54	14.5	2.7	11.8	16.8	34.9
21	46	15.6	6.2	9.4	18.8	38.4
27	31	9.6	3.3	6.3	20.0	36.7
24	6	10.7	2.8	7.9	18.8	38.6
25	95	16.5	6.2	10.3	18.9	34.6
29	83	25.5	4.2	21.4	13.8	31.7

Elevation.

Fringed amaranth grows between 1,640 and 5,577 ft (500-1700 m) in elevation (FNA 2023a).

Soils.

Fringed amaranth typically grows in well-draining soils, mostly of sand, but can also be found in clay, silt, and gravely deposits (BLM SOS 2022). The literature does not describe any direct associations with biological soil crusts.

ECOLOGY AND BIOLOGY

Fringed amaranth is an early successional summer annual that does well in disturbed sites. Like other summer annuals, fringed amaranth has C4 photosynthesis, which aids in a faster growth rate during high temperatures (Mackay 2013). Fringed amaranth is well adapted to high temperatures and grows in a variety of light conditions (Mackay 2013).

Reproduction.

Breeding System.

The breeding system of fringed amaranth has not been studied. Some monecious *Amaranthus* species are self-compatible, in addition to being wind-pollinated (Assad et al. 2017).

Reproductive Phenology.

Fringed amaranth typically begins to bud from July to September and flowers between August and November (Calflora 2023, SEINet 2023a). It may produce fruit throughout the flowering period until January before releasing seed (iNaturalist 2023).

Pollination.

Fringed amaranth, like other Amaranthus species, is wind pollinated. The wind-born pollen of many species in the genus Amaranthus is a major source of allergens and can sometimes contribute to hay fever (Austin 2010).

Seed and Seedling Ecology.

In the Mojave and other deserts, fringed amaranth relies heavily on rain and warmer temperatures to germinate. Typically, daytime temperatures need to exceed 20°C (68°F) for optimal germination, thus fringed amaranth is considered a summer annual (Went 1948). One study found that 6 mm of rain was sufficient to germinate fringed amaranth and that sometimes

a second germination event would occur during late summer, but not if rains were too heavy (23 - 50mm) (Juhren et al. 1956).

A study investigating seed storage of plants from many habitats classified fringed amaranth as a species with long-lived seed. Fringed amaranth seeds are able to survive in soil seed banks for ~20 years, though details of this estimate are not described (Went 1957, as cited in Kozlowski 2012).

There is no literature describing the dispersal method of seed for fringed amaranth. Though not directly specified, the growth of seedlings of fringed amaranth is likely very quick, considering its early successional growth traits and annual life cycle.

Species Interactions.

Belowground Interactions.

A study in the Mojave Desert found that fringed amaranth was colonized by hyphae, but not arbuscules or vesicles (functional organs) of mycorrhizal fungi. Therefore, mycorrhizae are present around the roots, but do not strongly interact with fringed amaranth (Titus et al. 2002).

Wildlife and Livestock Use.

Very few wildlife species are cited in the literature as users of fringed amaranth. Typical seed eaters in the Mojave include rodents and insects (Suazo et al. 2013). Ants, which select seed based on constraints on the size of their mandibles (Davidson 1977), were found to collect the seeds of fringed amaranth in a study conducted in New Mexico (Gordon 1993). Fringed amaranth was found in cheek pouches and within stomach contents of Kangaroo rats (*Diopodomys merriami*) (Soholt 1973).

Other Notable Species Interactions.

Fringed amaranth grows abundantly underneath desert shrubs, with these plants comprising up to three quarters of the total number of individuals within one population (Went 1948, Soholt 1973).

Fringed amaranth is a potential host plant of several lepidopteran species including the common sootywing (*Pholisora catullus*), white-lined sphinx (*Hyles lineata*), armyworm moth (*Mythimna unipuncta*), subterranean dart (*Feltia subterranea*), Ipsilon dart (*Agrotis ipsilon*), corn earworm moth (*Helicoverpa zea*), salt marsh moth (*Estigmene acrea*), garden webworm moth (*Achyra rantalis*), common gray (*Anavitrinella pampinaria*), yellowstriped armyworm moth (*Spodoptera ornithogalli*), Hawaiian beet webworm (*Spoladea recivalis*), lantana stick caterpillar (*Neogalea sunia*), and somber carpet (*Disclisioprocta stellata*) (Calscape 2023).

Disturbance Ecology.

Fringed amaranth is considered an early successional species which can spread in and from disturbed areas. Its ability to spread from cultivated fields in San Jose Del Cabo Oasis, MX, outside its native range, was noted by De La Luz et al. (1997).

There is not much information on how fringed amaranth responds to fire. However, one study mentioned fringed amaranth was a fire follower, as it was one of the first species to appear and flower after a fire in San Diego, California (Tratz and Vogl 1975).

Ethnobotany.

The Cahuilla tribe uses fringed amaranth for food. The seed is ground into flour and used to create an edible porridge. The greens are boiled and eaten or used as potherbs (Bean and Saubel 1972). Other species in the genus are

popularized as a celiac-friendly wheat grain substitute (Mackay 2013).

Horticulture.

According to Calscape, a California native plant guide by the California Native Plant Society, there are currently no nurseries that carry fringed amaranth seeds or seedlings (Calscape 2023).

DEVELOPING A SEED SUPPLY

A robust and stable supply of genetically appropriate seed is needed to meet restoration demands in response to expanding environmental stressors from land degradation, invasive species, and climate change. Restoration success is, in part, predicated on applying the right seed in the right place, at the right time (PCA 2015). Developing a restoration seed supply involves coordination across many partners in all steps of the process: from conducting wildland collections to propagating materials in nurseries and agricultural fields to eventual seeding or outplanting at restoration sites. Appropriate protocols for preserving genetic diversity and adaptive capacity should be in place (Erickson and Halford 2020) and seed origin should be documented for certification purposes and other seed planning considerations.

Seed Sourcing.

Seed sourcing can influence restoration outcomes due to local adaptation (Custer et al. 2022), landscape genetic patterns (Massatti et al. 2020, Shryock et al. 2021) and differing ability to adapt to current and future climate conditions (Bucharova et al. 2019). However, there has been relatively little research evaluating seed sourcing strategies in actual restoration settings where many additional factors influence performance (Pizza et al. 2023). While non-local sources can perform well in meeting initial restoration goals such as establishment and productivity (Pizza et al. 2023), evidence of local adaptation and its influence on restoration outcomes can take decades to emerge for long-lived species (Germino et al. 2019). Further, plants have coevolved with interacting organisms, such as pollinators and herbivores, that can exhibit preferential behavior for local materials (Bucharova et al. 2016, 2022).

Empirical seed transfer zones have not been developed for fringed amaranth. The Desert Southwest Provisional Seed Zones (PSZs) may be used to plan seed sourcing in the absence of species-specific information. The Desert Southwest PSZs use twelve climatic variables that drive local adaptation to define areas within which plant materials may be transferred with higher probability of successful establishment and reduced risk of introducing maladapted ecotypes (Shryock et al. 2018). Overlaying PSZs with Level III ecoregions can serve to further narrow seed transfer by identifying areas of both climate similarity inherent in the PSZs and ecological similarity captured by the ecoregion, namely vegetation and soils. Within the PSZs and ecoregion areas, further site-specific considerations such as soil, land use, species habitat and microclimate affinities, and plant community may be relevant to seed sourcing decisions.

The USGS Climate Distance Mapper Tool incorporates the Southwest Deserts Seed Transfer Zones with climate models and can serve to guide seed sourcing according to current and projected climate conditions.

Commercial Seed Availability and Germplasm Releases.

Fringed amaranth does not appear to be commonly available for purchase from large-scale commercial seed vendors. There have been no conservation plant releases of fringed amaranth.

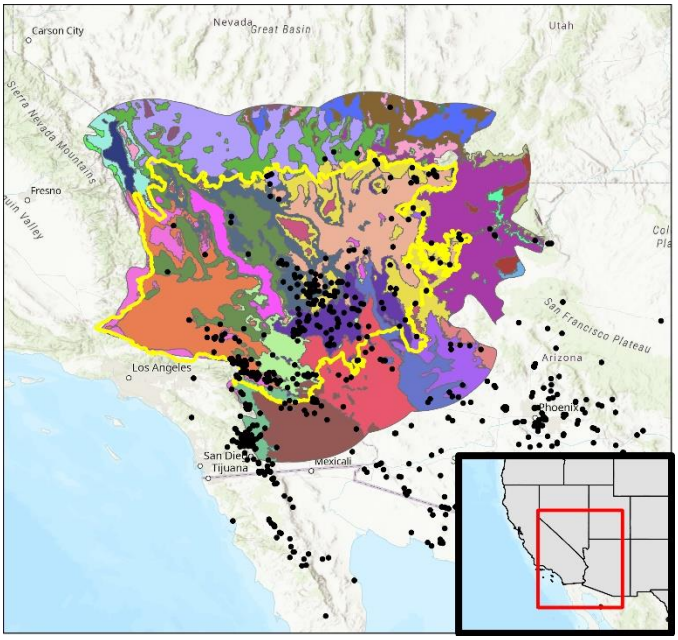

Figure 6: The distribution of fringed amaranth across the Desert Southwest Provisional Seed Zones (Shryock et al. 2018). Occurrences (black dots) are based on georeferenced herbarium specimens and verified observations (SEINet 2023). The Mojave Basin and Range Level III ecoregion (yellow outline) is buffered up to 100 km in all directions. PSZs do not always extend a full 100 km beyond the Mojave ecoregion.

Wildland Seed Collection.

Wildland seed collection involves visiting naturally occurring populations of target species to provide source seed for propagation, restoration, and research. Ethical practices are intended to prevent overharvesting by limiting harvests to no more than 20% of available seed (BLM 2021). However, in arid regions and in drought conditions, it may be best to adapt this guidance to collect no more than 10% of available seed due to limited regeneration and low-density populations (Asbell 2022, personal communication). Several practices are in place to ensure proper genetic diversity is captured from the source population. These include collecting from the entire population uniformly, sampling a diversity of phenotypes and microclimates, and collecting in various time windows to capture phenological and temporal diversity (BLM 2021).

Seed Collection Timing.

In the Mojave Desert, fringed amaranth is collected between September and November with the majority of collections occurring in September (BLM SOS 2022).

Collection Methods.

No collection methods specific to fringed amaranth were noted in the literature or personal communications. However, it is assumed that stripping mature seeds from the inflorescence by hand into a paper bag or other collection vessel would be an effective collection method for this species.

Post-Collection Management.

Immediately following collection, seeds should be properly managed to avoid damage or declines in viability during transport and temporary storage. Seed should be dried and ventilated to prevent molding (Pedrini and Dixon 2020). Ventilation can be achieved by collecting and storing seed in breathable containers, such as paper or cloth bags.

To dry material before storage or processing, spread it in a single layer on trays or newspaper indoors in a well-ventilated room, or outdoors in a shaded area (BLM 2021). Collected material should be visually inspected for seed-predating insects (Pedrini and Dixon 2020). If seed predation is observed, consider fumigation with No-Pest Strips. After collection, prevent exposure

to excessively hot or cold temperatures during transportation and temporary storage by keeping seed in a dry, insulated container (e.g., a cooler) in a shaded area while in the field (BLM 2021).

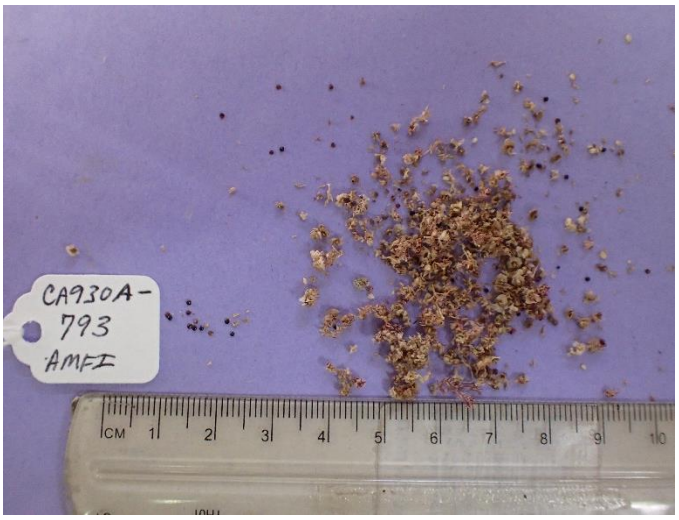

Figure 7: Collected seed and chaff material of fringed amaranth; scale shown in cm. Photo: BLM SOS CA930A

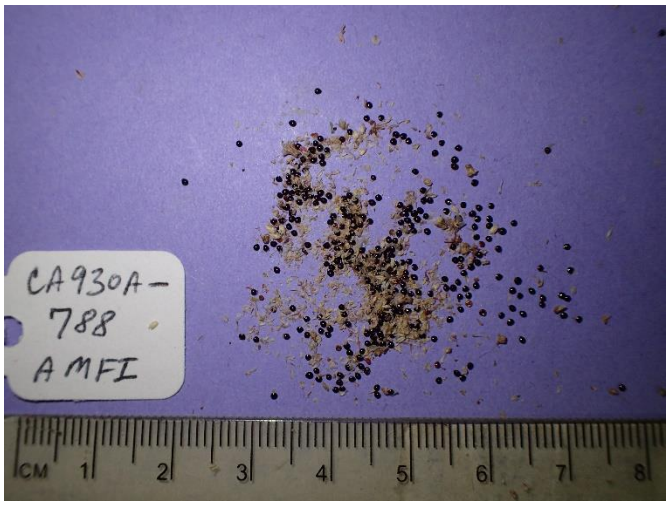

Figure 8: Bare seed and some chaff of fringed amaranth. Photo: BLM SOS CA930A

Seed Cleaning.

Fringed amaranth seeds are packed into a dehiscent capsule. This structure makes it very easy to collect and clean and a collection of many thousands of seeds can be processed in a short amount of time (Wall and MacDonald 2009).

To clean fringed amaranth seeds, rub the floral material across a #18 and #35 sieve to release the seed that is still within the capsules. Then, use a seed blower to separate the seed from chaffy material. The blower should be set to 1.5 speed and then increased to 1.75 to remove any sterile seeds (Wall and MacDonald 2009).

Seed Storage.

In general, seeds should be stored in cool and dry conditions, out of direct sunlight, to maintain viability. Optimal conditions for medium-term storage of orthodox seeds (up to 5 years) are 15% relative humidity and 15° C (59° F). For long-term storage (>5 years), completely dried seeds should be stored at -18° C (0° F) (De Vitis et al. 2020, Pedrini and Dixon 2020).

Fringed amaranth seed is orthodox (SER SID2023). No information on the longevity or quality of fringed amaranth under any duration or conditions of storage was found.

Seed Testing.

After collection, a representative sample of each seed lot must be tested in an appropriate seed lab to ensure purity and germination meet minimum standards defined by the Association of Official Seed Analysts (AOSA 2016) and species standards from state-level certification programs as available. A set of "principles and standards for native seeds in ecological restoration" (Pedrini and Dixon 2020) outlines further guidelines specific to native plants, including procedures for obtaining representative samples of seed lots and incorporation of dormancy measures into seed testing and labels.

The pure seed unit – a combined unit of seed and attached structures that is classified as pure seed as opposed to inert materials – for *Amaranthus* species is defined by AOSA as a "seed, with or without seed coat, and a piece of

broken seed, with or without seed coat, larger than one-half the original size" (AOSA 2016).

The AOSA does not specify guidelines for testing germination or purity of fringed amaranth seed, but one overall method for all congeners is described (AOSA 2016). The protocol for *Amaranthus* places seeds on blotting paper in covered petri dishes held at 20°C and 30°C (16/8-hour photoperiod). AOSA (2016) suggests using any of the following methods or a combination for viability testing: embryo excision tests, tetrazolium test, gibberellic acid, and, if hard-seeded, extending the germination period for 5 days (AOSA 2016).

Wildland Seed Yield and Quality.

Wild-collected fringed amaranth seed is generally high quality, with an average of 95% fill, 97% purity and 96% viability indicated by tetrazolium tests across 17 Seeds of Success collections (BLM SOS 2022, Table 2). Wild collections contain an average of over two million pure live seeds per pound (BLM SOS 2022, Table 2).

Table 2: Seed yield and quality of fringed amaranth seeds collected in the Mojave Basin and Range Ecoregion, cleaned by the Bend Seed Extractory and tested by the Oregon State Seed Laboratory or the USFS National Seed Laboratory (BLM SOS 2022). Fill (%) was measured using a 100 seed X-ray test. Viability (%) was measured using a tetrazolium chloride test.

	Mean	Range	Samples
Bulk weight (lbs)	0.79	0.13-2.63	17
Clean weight (lbs)	0.11	0.0083-9.394	17
Purity (%)	97	93-99	17
Fill (%)	95	90-99	17
Viability (%)	96	90-99	17
Pure live seeds/lb	2,183,526	1,745,578-2,716,560	17

Wildland Seed Certification.

The Association of Official Seed Certifying Agencies (AOSCA) sets the standards for seed certification and provides guidance on production, identification, distribution, and promotion of all certified seed, including pre-varietal germplasm. Pre-varietal germplasm (PVG) refers to seed or other propagation materials that have not been released as varieties (AOSCA 2022). Pre-varietal germplasm certification programs for source-identified materials exist in several states encompassing the Mojave Desert ecoregion including California (CCIA 2022), Utah (UTCIA 2015), and Nevada (NDA 2021). Arizona does not have a PVG certification process at this time. Source-Identified (SI) germplasm refers to seed collected directly from naturally occurring stands (G0), or seed grown from wildland-collected seed in agricultural seed increase fields (G1-Gx) that have not undergone any selective breeding or trait testing. These programs facilitate certification and documentation required for wildland-collected seed to be legally eligible for direct sale or seed increase in an agricultural setting. Certified SI seed will receive a yellow tag, also referred to as an SI-label, noting key information about the lot including the species, the generation of seed (G0-Gx), source location, elevation, seed zone, etc. (UTCIA 2015, NDA 2021, CCIA 2022).

Wildland seed collectors should be aware of documentation required for seed certification. The Seeds of Success data form and protocol (BLM 2021) include all appropriate information and procedures for site documentation and species identification verification to meet certification requirements for wildland sourced seed. Seed certifying agencies may also conduct site inspections of collection locations prior to certification—specific requirements for

inspections vary by state and are at the discretion of the certifying agency.

AGRICULTURAL SEED PRODUCTION

Fringed amaranth does not seem to be commonly grown in agricultural seed production, but there have been recent efforts to establish fields from the Mojave Desert wildland seed sources for use in regional restoration. It will likely grow well in full sun to partial shade in well-draining soil with a neutral pH (Calscape 2023).

Agricultural Seed Field Certification.

As with wildland source seed (see Wildland Seed Certification section), seed grown in an agricultural seed increase field must also be certified by an official seed certifying agency, where programs exist. Field grown seed is also certified and labeled as Source-Identified (SI), as long as it has not undergone selective breeding or testing. Seed field certification includes field inspection, seed testing for purity and germination (see Seed Testing section), and proof of certification for all source or parent seed used to start the field (AOSCA 2022). The SI-label or "yellow tag" for seed from a seed increase field denotes information about source seed, field location, and generation level (G1-Gx) indicating if there is a species-specific limitation of generations allowed to be grown from the original source (e.g., in a species with a three-generation limit, G1/G3, G2/G3, G3/3) (AOSCA 2022).

There are no species-specific certification standards for fringed amaranth in the states where it occurs.

Isolation Distances.

Sufficient isolation distances are required to prevent cross-pollination across seed production crops of fringed amaranth from different sources or other *Amaranthus* species. Table 3 summarizes the isolation distances required for PVG certification in Utah for outcrossing annual species (UCIA 2023). California, Nevada and Arizona do not specify these standards for Source Identified PVG seed of fringed amaranth.

Table 3: Crop years and isolation distance requirements for pre-varietal germplasm crops of fringed amaranth. CY= crop years, or the time that must elapse between removal of a species and replanting a different germplasm entity of the same species on the same land. I= isolation distance, or the required distance (in feet) between any potential contaminating sources of pollen**.**

	G1		G2		G3+	
State	CY	I	CY	I	CY	I
Utah	3	900-600	2	450-300	1	330-165

Site Preparation.

Fields should be as weed-free as possible prior to planting. Site preparation to reduce undesirable vegetation should be planned and implemented well in advance of field establishment (USDA NRCS 2004). If fields are uncultivated or fallow and have perennial or annual weeds, one or more years of intensive cultivation (i.e. cover cropping) and herbicide treatment may be necessary (USDA NRCS 2004). After managing undesirable species, final seedbed preparation can include shallow tilling followed by packing to promote a finely granulated, yet firm seedbed that allows soil to seed contact, as well as facilitation of capillary movement of soil moisture to support seedling development (USDA NRCS 2004).

No information about site preparation specific to fringed amaranth fields was found in the literature or through personal communications.

Seed Pre-treatments.

Fringed amaranth requires warmer summer-like temperatures to enhance germination. Growers investigated the best practices for germinating summer and winter annuals using a mix of seed pre-treatments and varying germination temperatures (Earsom 1979). They found that fringed amaranth germinated maximally at 40°C, but germination rate was highest when combined with a pre-treatment of heating seeds to 50°C followed by soaking and rinsing. Overall, pre-heating fringed amaranth seeds at 50°C yields high rates of germination at temperatures of 40°C and 35°C, regardless of if seeds were soaked or not (Earsom 1979). This finding is consistent with Went (1948), who found that this summer annual needs warm temperatures and does not require leaching to germinate (Went 1948).

Germination of fringed amaranth may vary depending on seed maturity and temperature conditions (MDLT 2022). Growers at the Mojave Desert Land Trust (MDLT) found that seeds harvested an early-stage (when stalks were still green) germinate better in greenhouse conditions (75-90°F on moist paper towel) and seeds harvested at a later-stage (when stalks are brown and senescing) germinate better closer to room temperature (75-80°F on moist paper towel). This may be a potential "bet-hedging strategy" that allows seeds to germinate under varying temperature regimes (MDLT 2022).

Seeding Techniques.

In a seed increase trial at Victor Valley College (VVC) in Victorville, CA, fringed amaranth seeds were hand-broadcast in June into three 16 x 25 ft plots. Each plot received approximately 0.9 grams of seed (Brooks and Gault 2023a).

Growers at MDLT sowed 12 g of fringed amaranth seed in a 100 ft^2 plot. Seeds were hand-sown by scuffing the ground, spreading seed along four rows, and covering the seed lightly with soil. Two of four rows were covered with Reemay fabric (woven polyester) to reduce granivory. The rows covered with the fabric had significantly higher germination compared to uncovered rows (Asbell 2023, personal communication).

There is no direct seeding rate nor suggested planting depth currently published for fringed amaranth. As an annual species, fringed amaranth is likely amenable to direct sowing rather than plug production.

Early summer is assumed to be an optimal time to seed fringed amaranth once soil temperatures rise above 20°C.

Establishment and Growth.

At MDLT, establishment rates varied and were actually lower in plots with higher germination due to herbivory. In the covered plots, establishment rates were 43-48%, as numerous seedlings were eaten after the Reemay fabric was removed. In the uncovered plots, the establishment rates were 63-85% (Asbell 2023, personal communication).

The Irrigation section below includes a summary of how different irrigation treatments impacted establishment at VVC.

Weed Control.

Weeds can be manually removed or carefully spot-sprayed with non-selective herbicide as they emerge. In smaller fields, hand rogueing weeds can be sufficient (Hagman 2023, personal communication).

Since *Amaranthus* sp. are often considered weeds in agricultural settings, they are included as targets for broadleaf herbicides. Chemical treatments must be performed carefully to avoid damage to fringed amaranth.

There are a limited number of herbicides registered and labeled for use on native plant crops. See the Native Seed Production guide from the Tucson Plant Materials Center (USDA NRCS 2004) for further details on weed management in native seed production fields.

Pest Management.

Growers at MDLT found that fringed amaranth became infested with beet armyworm moth larvae (*Spodoptera exigua*) (MDLT 2022). The caterpillars consumed the leaves and flowers (MDLT 2022). Treatment with *Bacillus thuringiensis* (Bt; a bacterium used as a natural insecticide) was not effective in this case (MDLT 2022).

Small mammal herbivory was also an issue for the MDLT plots. Metal flashing and plastic sheeting around the perimeter of the plots helped exclude herbivores (MDLT 2022). However, small mammals (likely mice or rats) were able to make it past the perimeter and consume young plants, reducing overall establishment (Asbell 2023, personal communication).

Pollination Management.

Since fringed amaranth is wind pollinated, plants should be able to readily exchange pollen within a seed production field without employing management strategies.

Figure 9: Trial seed increase plots of fringed amaranth at the Mojave Desert Land Trust. Photo: Madena Asbell

Irrigation.

At MDLT, the fringed amaranth plots were initially watered by hand followed by drip irrigation one hour to support germination and establishment. After the plants established, they were watered by hand or with an oscillator every two to three days for ten days. Later, water was reduced to once per week with drip irrigation or oscillator until harvest (Asbell 2023, personal communication).

Growers at VVC conducted a trial to study the effects of varied amounts of water for irrigation of fringed amaranth seed increase plots (Brooks and Gault 2023a). Three variables of different amounts of irrigation administered via drip lines throughout the growing period were implemented for this trial – a 'baseline' treatment represented the high end of the warm season precipitation total range in the Mojave Desert at

125 mm (4.9 inches), a 'supplemental' treatment represented a 50% increase from the control at 187 mm (7.4 inches), and an 'excess' treatment representing an increase of 100% at 250 mm (9.8 inches). All treatments were irrigated for the first five days following seeding to support germination, after which irrigation was administered two times per week for one-hour intervals. Irrigation was applied from June-August until water amounts for each treatment were reached. The 'baseline' treatment had the highest number of plants to germinate and establish, while the 'excess' treatment had the highest establishment rate of germinants (Table 4). Seed yields from this trial are unknown as seed is still being processed (Brooks and Gault 2023a).

Table 4: Preliminary results from irrigation trials on fringed amaranth seed increase plots at Victor Valley College. Number of plants reported is an approximate count.

Treatment	Total H_2O (in)	Plants Germinated	Plants Established (%)
Baseline	4.9	76	58 (76%)
Supplemental	7.4	40	26 (65%)
Excess	9.8	59	48 (81%)

A study comparing water adaptations of summer versus winter annuals found that the roots of summer annuals penetrated much deeper into the soils and were much more fibrous (Forseth et al. 1984). The roots of summer annuals were often divided into two zones, one close to the surface and one lower, to accommodate for heavy rains versus light rains (Forseth et al. 1984).

Many growers apply uniform watering techniques regardless of species due to their set infrastructure and labor resources. For example, at the Tucson Plant Materials Center, all fields are watered with flood irrigation (Dial 2023, personal communication). After seeding, fields are irrigated to maintain a moist soil surface and avoid soil crusting that would interfere with germination. Once seeds are established, fields are flooded approximately every four weeks during the growing season. Irrigation frequently will depend on heat and precipitation levels and may be as frequent as every two weeks during the hottest part of the year to avoid stressing plants and lowering seed yield (Dial 2023, personal communication).

Other growers administer water via drip irrigation and find flood irrigation does not adequately penetrate into soil, resulting in significant evaporation in aridland farm settings (Hagman 2023, personal communication).

Seed Harvesting.

Fringed amaranth crops exhibit indeterminant flowering and seed ripening. At VVC, seed is harvested in the fall or early winter by cutting the flower stalks, or even the whole plant, and placing them in a bag. It can be difficult to determine optimal harvesting time due to the indeterminate flower and fruit development within single plants (Brooks and Gault 2023, personal communication).

To investigate optimal harvest times, the MDLT trialed harvesting fringed amaranth at two different collection windows: 1) early – when plants were in peak bloom and had not yet released their seed and 2) late – when plants were brown and releasing their seed (MDLT 2022). The germination and viability of the early and late seed lots were compared to assess if seed could be harvested in one event during early reproductive stages or if multiple harvest events are required to capture viable seed across the indeterminate seeding period. To assess germination, MDLT growers germinated 100 seeds from each collection (early and late) on a moist paper towel. One 100-seed sample was kept indoors at room temperature and another sample from each collection was kept in a greenhouse where temperatures reached up to 90 ° F. They found that early seeds had higher germination than late seeds in the warmer greenhouse environment while late seeds had higher germination at room temperature. Further comparisons of germination in soil and cut tests to assess seed fill revealed that there were minimal differences in seed germination rates or visually assessed seed fill between early- and late-harvested seeds. These results suggest that a single harvest period early in the season may be sufficient to capture viable seeds prior to dispersal. However, more trials are needed to assess variability in germination response based on harvest time. If seeds harvested at different ripening stages exhibit differing responses to temperature, then it would be beneficial to complete multiple harvests to capture the range of adaptive germination strategies (MDLT 2022).

Small-scale seed increase fields may be harvested by hand following similar methods as wildland collections (see Collection Methods). No methods for mechanical harvests were noted in the literature or personal communications.

Seed Yields and Stand Life.

The stand life for an annual will be one year for the target generation class. Fringed amaranth readily volunteers from the seed bank in seed increase plots (Brooks and Gault 2023, personal communication). Removing volunteer plants of uncertain generation class will help prevent having a mixed-generation crop. Volunteer plants can also be cultivated for additional harvest if desired (Brooks and Gault 2023, personal communication).

Yield from the 100 ft^2 fringed amaranth plot at MDLT was 4 lbs.

NURSERY PRACTICE

Nursery propagation is not commonly practiced for annual species, except in some cases for small-scale seed increase or starting seedlings from limited seed stock in preparation for agricultural seed production (Brooks and Gault 2023, personal communication).

No specific descriptions of nursery practices for fringed amaranth were found in the literature or personal communications. If needed, techniques for other desert annuals can be referenced. Seeds can be planted in flats filled with a well-draining soil (including perlite, sand, and/or coir in the potting mix). Seeds can be sprinkled over the soil surface and lightly pressed to improve seed-soil contact. Flats should be kept moist during the germination and seedling emergence periods. After seedlings are fully emerged, watering can be reduced (USDA NRCS 2023).

REVEGETATION AND RESTORATION

Fringed amaranth has not been documented in wildland restoration or revegetation.

In general, annual plants like fringed amaranth are more likely to be restored via direct seeding and indirectly through establishing perennial plants or improving site conditions (Abella 2017).

Wildland Seeding and Planting.

Wildland Seedings.

See Agricultural Seed Production for further information on potentially transferrable methods for wildland seedings.

Wildland Plantings.

Annual species are generally not recommended as plug transplants and will likely perform better with direct seeding methods (Abella 2017).

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RESOURCES

AOSCA NATIVE PLANT CONNECTION

https://www.aosca.org/wp-content/uploads/Documents/AOSCANativePlantConnectionBrochure_AddressUpdated_27Mar2017.pdf

BLM SEED COLLECTION MANUAL

https://www.blm.gov/sites/default/files/docs/2021-12/SOS%20Technical%20Protocol.pdf

OMERNIK LEVEL III ECOREGIONS

https://www.epa.gov/eco-research/level-iii-and-iv-ecoregions-continental-united-states

CLIMATE SMART RESTORATION TOOL

https://climaterestorationtool.org/csrt/

MOJAVE SEED TRANSFER ZONES

https://www.sciencebase.gov/catalog/item/5ea88c8482cefae35a1faf16

MOJAVE SEED MENUS

https://rconnect.usgs.gov/MojaveSeedMenu/

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