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Fiddling Around with Fiddlenecks: Seed Collection, Processing, and Propagation of *Amsinckia tessellata* and *Lappula occidentalis*

Derek Tilley, Mary Wolf, Carla Corea, Jennifer Salguero

Derek Tilley, Aberdeen PMC Manager; Mary Wolf, Aberdeen PMC Agronomist; Carla Corea, Cal Poly, Pomona; Jennifer Salguero, Cal Poly, Humbolt. 1691 A South 2700 West, Aberdeen, Idaho 83210; derek.tilley@usda.gov

ABSTRACT

Native forb plant material options for restoration and reclamation projects in semiarid environments are limited in the Intermountain West, USA. To facilitate the adoption and use of novel species by seed producers and end users, an understanding of basic plant information like germination, establishment, and production potential is needed. Bristly fiddleneck (*Amsinckia tessellata* A. Gray) and flatspine stickseed (*Lappula occidentalis* [S. Watson] Greene) are early seral native forbs of the fiddleneck family (Boraginaceae) that may have potential as conservation species due to their ability to establish in highly disturbed environments and compete against invasive annual grasses. We conducted a series of laboratory and field experiments with bristly fiddleneck and flatspine stickseed to examine germination requirements, wildland seed collection methods, and seed cleaning techniques. We also conducted a preliminary germination trial on flatspine stickseed to compare germination in an aerated water bath (bubbler) with germination in a standard Petri dish environment. The highest germination of bristly fiddleneck (93%) was achieved with diurnal conditions and 18/10 °C temperatures in the bubbler. Seed germinated readily when planted on the soil surface on loam, fine sandy loam, and clay loam soils but showed poor emergence when planted at 1 and 2 cm depths. Harvesting from wildland stands using a racquet and hopper was faster and produced greater seed yields than clipping stems. We achieved an average germination of 86% for flatspine stickseed in the bubbler compared to zero germination in germination boxes. Seed cleaning methods for both species are also detailed.

Key Words
forbs, germination, seeding depth, seedling vigor

Nomenclature
USDA NRCS (2023)

INTRODUCTION

Native forb plant materials are needed to meet restoration and conservation demands in the Intermountain West of North America (Shaw et al., 2005). Large-scale invasion of introduced exotic grasses such as cheatgrass (*Bromus tectorum*) has shortened local fire recurrence intervals and increased the size and scope of wildfires in the region (Pilliod et al., 2017). Fire regime changes from cheatgrass invasion have decreased native species plant diversity (Humphrey and Schupp, 2001; Mahood and Balch, 2019) and diminished site resilience (Chambers et al., 2007). Cheatgrass has several traits that allow it to invade and persist, including low-temperature germination and quick establishment and reproduction (Barak et al., 2015). Concurrent germination of competitive native species has been suggested as a desirable trait in native plant materials, as plants that are ecologically and phenologically similar to invasives can provide direct competition at key growth stages (Forbis, 2010; Barak et al., 2015; Csákvári et al., 2023). To date, it has been difficult to locate suitable species that germinate at low temperatures to compete against cheatgrass (Barak et al., 2015).

Spatiotemporal functional group diversity has been shown to improve site resilience (Tilman and Downing, 1994; Pokorny et al., 2015). One particularly underrepresented group of plant materials with the potential to meet these needs is the early seral species (Tilley et al., 2022a). Because they have evolved to be adapted to disturbed conditions, early seral natives can compete better against invasive annuals than late seral species. Early seral natives often show better establishment in areas invaded by exotic annual grasses than late seral species (Uselman et al., 2015), and they have been shown to reduce biomass and seed production of invasives (Leger et al., 2014; Perry et al., 2009). Early seral forbs have also been shown to benefit native pollinators. For example, the use of early seral forbs in restoration seed mixes in Wyoming gas fields increased insect abundance and biodiversity compared to non-restored reference sites (Ballard et al., 2013; Curran et al., 2022).

Figure 1. Scorpioid cyme inflorescence of bristly fiddleneck. Photo by Mary Wolf.

Bristly fiddleneck (*Amsinckia tessellata* A. Gray) is a native annual forb that appears to meet several of the desired criteria for early seral plant materials. Bristly fiddleneck is widespread, occurring in all western states from New Mexico north to Idaho and into British Columbia (USDA NRCS, 2023). Plants are 30 to 60 cm (12 to 24 in) tall with flowers arranged in a scorpioid cyme common to the Boraginaceae (Figure 1). This species is characterized by small flowers, homostyly, and rough, bumpy (tessellate) nutlets (Figure 2) (Ray and Chisaki 1957; Welsh et al., 2003). Bristly fiddleneck is largely self-pollinated, but cross-pollination and even hybridization with other *Amsinckia* have been observed (Ray and Chisaki, 1957). Despite being primarily self-pollinated, visitation to the flowers by the native bees *Anthophora neglecta*, *Melecta edwardsii*, and *Osmia* spp. has been documented (DiscoverLife, 2023). Bristly fiddleneck has numerous useful restoration qualities. It has been shown to significantly reduce the biomass of red brome (*Bromus rubens*) in a controlled greenhouse study (Abella et al., 2011), while Leger et al. (2014) showed bristly fiddleneck reduced cheatgrass biomass by 97% and reduced seed production significantly in greenhouse trials.

Figure 2. Bristly fiddleneck seeds (nutlets). Scale marks are 1 mm. Photo by Derek Tilley.

Flatspine stickseed (*Lappula occidentalis* [S. Watson] Greene) is an annual native forb growing between 10 to 80 cm tall (3.9 in. to 24 in) (Figure 3). Like bristly fiddleneck, flatspine stickseed also bears its flowers in a scorpioid "fiddleneck" cyme. Rough stiff hair is found throughout the plant including both stems and leaves. Flatspine stickseed has tiny white to pale blue clustered flowers. Its fruit is a schizocarp comprised of 4 nutlets which are semi-fused together forming a cluster with a length of 2-3 mm (.07 to .11 in). The nutlets are separated by a single row of hooked spines, and dehisce as they ripen and mature, turning brown or black in color. Flowering occurs in early spring (March) and throughout early autumn (September).

Information on basic establishment and seed production is needed to facilitate the possible adoption of novel species in the seed industry (Winters, 2023). Likewise, basic germination and adaptation information is needed to guide restorationists with seeding efforts. For example, information is needed on soil adaptation and planting depth to provide recommendations for conservation practices (Rawlins et al., 2009; Bushman et al., 2015; Tilley et al., 2022b; Ogle et al, 2023). Limited germination information for bristly fiddleneck is presently available. Forbis (2010) showed bristly fiddleneck germinates better in light than dark, and cold moist stratification resulted in slight increases in germination but not significantly so. Leger et al. (2014) also indicated bristly fiddleneck is capable of germinating during cold periods and does not require stratification, but cold temperature limits for the species were not defined.

Figure 3. Flatspine stickseed (left) grows in disturbed sites throughout western North America. The seeds (right) bear hooked spines to facilitate dispersal. Scale bar is 0.5 mm. Photos by Derek Tilley.

Seed production requirements can be a limiting factor in acceptance and seed availability (McCormick et al., 2021). If highly specialized equipment and methods are required, the cost of seed production can become prohibitive to end users or unprofitable to producers. Wildland harvesting is currently the only means of obtaining bristly fiddleneck seed, though small-scale production has been initiated for government agencies (de Queiroz et al., 2021). De Queiroz et al. (2021) suggested swathing and windrowing of bristly fiddleneck as possibly more efficient than hand harvesting. They also indicated a 100% increase in seed yield when growing bristly fiddleneck plants on weed barrier fabric compared to plants grown without fabric, though it was not indicated if this increase was due to better production or because it was possible to sweep shattered seed off the fabric.

There are several considerations to overcome before seed of these species can be produced commercially. For example, indeterminate seed maturation, coupled with seed that readily shatters, complicates seed harvest. Single-harvest methods (direct combining) are unlikely to achieve maximum yields because much of the seed is lost either to shatter or because of indiscriminate collection of immature seed along with the ripe seed. Additionally, both species have leaves and stems covered with stiff hairs and bristles (Figure 4) making hand harvest and mechanized seed processing difficult and potentially hazardous.

Figure 4. Bristly fiddleneck vegetation is covered with sharp, bristly hairs that can irritate skin and eyes. Scale bar is 0.5 mm (L) and 0.2 mm (R). Photos by Derek Tilley.

To address obstacles to the successful seed production of bristly fiddleneck and flatspine stickseed, we document here useful anecdotal observations regarding wildland harvesting and seed cleaning for both species. We further conducted germination and emergence experiments on bristly fiddleneck to provide basic information to guide future usage.

MATERIALS AND METHODS

Wildland seed harvest

To minimize injury from fiddleneck bristles, we wore protective gear including a face mask, goggles, gloves, full body coveralls, and irrigation boots (Figure 5). A common seed collection method is to clip stems just below the inflorescence. To maximize seed yield, we targeted stems on which the bottommost seeds (most mature) were shattering or had already shattered. Stems were stored in paper sacks or laid out on a shop floor on butcher paper and allowed to dry from two to several weeks in a well-ventilated room. An alternate harvest method uses a racquet to beat seed heads and a hopper to collect the dislodged seed (Tilley et al., 2022b; Jensen, 2004). Raquet and hopper methods allow for multiple harvests and require less hands-on removal of stems. Racquet harvesting also does not create as much inert biomass from stems and leaves as the clipping method (Figure 6).

Figure 5. Wildland seed harvesting of bristly fiddleneck requires protective clothing and eyewear. Photo by Mary Wolf.

Figure 6. Raw collected material of bristly fiddleneck harvested by racquet and hopper (left) and clipping (right). Material collected using a racquet and hopper can be directly fed into cleaning equipment, while clipped stems require crushing and rough screening. Photos by Derek Tilley.

To compare the efficiency and efficacy of these methods, we collected bristly fiddleneck seeds from two wildland stands, Rinker Rock Creek Ranch located in the Wood River Valley, Blaine County, Idaho, and Curlew National Grassland, Oneida County, Idaho. Both stands were roughly 3x10 m (10x30 ft) of densely populated plants. At the Rock Creek site, we completed a single harvest using the clipping method. The time spent harvesting was approximately 60 minutes. At the Curlew National Grassland site, we made two harvests (1 week apart) using the racquet and hopper method. Each harvest took approximately 10 minutes.

Figure 7. Flatspine stickseed nutlets bear hooked spines that let them cling to clothing and fur. Photo by Derek Tilley.

Flatspine stickseed can be harvested by cutting off the inflorescence of mature plants or by pulling the entire plant from the ground. The plants are typically too short in stature for racquet harvesting to be effective. Collections were made on June 20, 2024, at a site near Jerome, Idaho. *Lappula* nutlets, much like fiddleneck, shatter from their clusters when they are ripe and attach themselves to any surface. Using gloves to cut or pull the plant is necessary to avoid irritation caused by the hooked spines found on the nutlets (Figure 7).

Seed cleaning

Bristly fiddleneck seed cleaning requires brushing, milling, or other methods to dislodge seed from the flowers, which results in airborne bristles. To reduce the risk of irritation to the skin, eyes, and lungs, we wore protective gear as described above during rough cleaning. Paper bags containing the stem clipping inflorescences were placed in a large, galvanized tub or a large cardboard box and repeatedly stepped on to break stems and dislodge seed. To minimize bristles released into the air, this was done slowly and gently. Crushed material was then hand-screened to remove larger stem and leaf pieces using a 6.3 or 13 mm (0.25 or 0.5 in) screen. Material collected using a racquet and hopper did not contain stem material and did not need to be crushed or pre-screened.

Material from both harvesting methods was threshed using a Westrup laboratory brush machine (Slagelse, Denmark) with the gate closed to allow the seed to fall through the drum to the tub below (Figure 8). An airlift vacuum system was applied to suck bristles and dust away from the user. After threshing, the seed was separated from inert material using a Westrup 3-screen cleaner (Slagelse, Denmark) with a 2.1 mm (0.08 in) upper screen to remove larger inert material and a 6x24 bottom screen for smaller matter. An airflow column was also used to remove dust and unfilled, light seed. We repeated the air screen process 3 times to maximize purity. Following processing, we weighed 4 replications of 1,000 seeds from 2 sources, Baker City, OR, and Curlew National Grassland, ID to calculate the average seeds per pound.

Figure 8. Processing of small collections of bristly fiddleneck seed collected by clipping. Clipped stems are crushed while still in the bag followed by rough screening to remove stems. The remaining material is then processed using a brush machine and air-screen separator. Photos by Derek Tilley.

For flatspine stickseed, we dried entire harvested plants for 14 days in a well-ventilated area. Once dried they were stepped on, as described above, to dislodge the seeds from the plant and break up stems. The crushed material was then sieved, in the manner described for fiddleneck, to separate bigger pieces of plant material from the seeds. The crushed and sieved matter was then threshed in the brush machine with the gate closed to allow seeds to fall through the drum below. After threshing, we separated inert material from the seed using the 3-screen cleaner with a 3.55 mm (0.14 in.) upper screen to remove larger material, a 3.15mm (0.12 in.) middle screen, and a 1.15 mm (0.4 in.) screen at the bottom to remove fine inert material. Light air was used to remove dust and light seeds. Once this process was complete, we weighed 4 replications of 1,000 seeds to calculate the average number of seeds per pound.

Germination

Seed harvesting by clipping stems allows for post-harvest ripening and increases seed yields for some species (Tilley et al., 2022b). However, we observed a significant number of green nutlet clusters from clipped bristly fiddleneck material. To test whether the green nutlets had achieved full maturation and were viable, we conducted a non-replicated germination test. Thirty (30) clusters of 4 green seeds were placed in mesh bags in an aerated water bath next to 40 dark, ripe seeds in an adjacent bag per Tilley and Picket (2021); see below for full details. Significant differences were obvious in only 4 days; 7 out of 120 (6%) of the green seeds germinated compared to 19 of 40 (48%) ripe seeds. These findings agree with de Queiroz et al. (2021) who indicated bristly fiddleneck should be cut for harvest when the inflorescence is dry. Based on these results we used only fully ripe seed for the following experiments.

To better understand bristly fiddleneck germination and its potential as an early successional forb for restoration, trials were conducted to determine if germination occurs at temperatures comparable to cheatgrass germination temperatures. Additionally, aerated water bath (bubbler) trials were conducted to determine if seed germination could be improved and synchronized (Tilley, 2013; Tilley and Pickett, 2021). Seed for the germination trial was collected from a stand at Baker City, OR in 2022. In total, we examined 9 germination treatments with seeds placed on blotter paper in 7 treatments, plus 2 treatments in bubblers (Table 1). All treatments received 4 replications of 50 seeds. Three temperature regimes were tested: a constant warm condition 22 °C (72 °F), cooler with fluctuating day/night temperatures 18/10 °C (64/50 °F), and a very cold 2 °C (36 °F) constant temperature. Increased germination observed in bubblers may have resulted from decreased fungal pressure. To test if fungus was a significant factor, we included a bleach treatment for seeds germinated on blotter paper in the 18/10 °C, 22 °C, and 2 °C environments. Seed was soaked for 10 minutes in a 1:8 solution of bleach and distilled water followed by a 2-minute rinse under tap water (Luna et al., 2009). Finally, we included a 30-day cold/moist stratification (2 °C) treatment followed by germination in the 18/10 °C blotter environment.

Table 1. Bristly fiddleneck germination treatments, temperatures, growing media, and pretreatments.

Treatment Name	Temperature (°C)	Growing Medium	Stratification
Blotter2C	2	Blotter paper	No
Blotter2C+Blch	2	Blotter paper	No
Blotter18/10C	18/10	Blotter paper	No
Blotter18/10C+Blch	18/10	Blotter paper	No
Bubbler18/10C	18/10	Aerated water	No
Strat+Blot18/10C	18/10	Blotter paper	Yes
Blotter22C	22	Blotter paper	No
Blotter22C+Blch	22	Blotter paper	No
Bubbler22C	22	Aerated water	No

For the blotter treatments, we used 95x70x45 mm plastic germination boxes (Pro-Mold Inc., Kipton, OH) with dimpled blue blotter paper rested on Versa-Pak germination paper soaked with distilled water (Figure 9). For the bubbler treatments, we followed Tilley and Picket (2021) by submerging seeds in a fine mesh bag into a 0.95 L Mason jar filled with 500 mL distilled water. Aeration was added with a Profile 1500 aquarium air pump (Spectrum Brands Pet LLC, Blacksburg, VA) fitted with a 2.5 cm bubbling air stone (Figure 9) with all 4 replications placed in the same jar but kept separate in fine mesh bags. All treatments were subjected to a 15 hr light, 9 hr dark cycle. The germination trial was conducted in a Percival germination chamber (Percival Scientific, Inc., Perry, IA) except for the 22 °C (72 °F) treatments, which were conducted at room temperature under a 15-hour light/9-hour dark cycle provided by LED grow lights from an AeroGarden Bounty Basic home hydroponics unit (AeroGrow International, Inc., Boulder, CO). Seedlings were counted as germinated if the cotyledon, seed coat, or hypocotyl were visible. Seedlings were removed after each counting.

For flatspine stickseed, we compared two germination environments: germination in germination boxes on blotter paper versus germination in a bubbler. Both treatments were conducted at room temperature, 22 °C (72 °F), under a 15-hour light/9-hour dark cycle. The seed was not pre-washed with bleach. Germination boxes were lined with cellulose wadding planting medium and wetted and sealed. For flatspine stickseed, we did not use blotter paper as described for bristly fiddleneck but placed the seed directly on the damp cellulose. Each germination box was seeded with 40 individual nutlets. The bubbler treatment was conducted as described above using 40 nutlets per replication. Each treatment was replicated 6 times. Germinants were counted 13 days after initiation and counted as germinated if cotyledons or radicles were > 2mm.

Emergence

Bristly fiddleneck seedling emergence from three seeding depths was evaluated in soils of three texture classes, a Declo fine sandy loam (FSL), Declo loam (L), and a Fingal clay loam (CL), collected from sites in Southeastern Idaho. The soil was gently broken up and passed through 2.1 mm (0.08 in) screens to remove larger clods, weed seeds, and other inert material. We filled 10x10 cm (4-in) pots with soil to a depth of 5 cm (2 in), added 50 seeds, and then buried the seeds to the appropriate depth of 0, 1, or 2 cm (0, 0.4 or 0.8 in) (Figure 10). The pots were placed in the greenhouse in a randomized complete block design with 4 replications. Greenhouse temperatures ranged daily from 15 to 30 °C (60 to 85 °F). Pots were irrigated via overhead sprinklers for 20 minutes daily. We counted seedling emergence weekly for 6 weeks (anticipating longer emergence time from deeper placement). Seedlings were counted as “emerged” if the cotyledons were visible. Seedlings were removed at each counting.

Figure 10. We tested seedling emergence of bristly fiddleneck seed planted at 3 depths (0, 1 and 2 cm) in 3 soil textures: a Declo fine sandy loam (FSL), Declo loam (L) and a Fingal clay loam (CL). Photo by Derek Tilley.

We did not conduct a seedling emergence experiment using flatspine stickseed.

Experimental Analysis
Data for all experiments were tested for normality using a Shapiro-Wilk test to determine the appropriate test to analyze variance. Data from the germination experiment were not normally distributed, therefore final germination (FG) and coefficient of germination (CG) data were transformed using the square root transformation function in Statistix 10 Analytical Software (Tallahassee, FL). Transformed data were analyzed using a one-way analysis of variance (ANOVA). Means with differences at 5% level of probability were separated using Tukey's Honest Significant Difference at $P < 0.05$. The seedling emergence experiment was analyzed using the factorial AOV procedure in Statistix 10 with depth and soil texture as factors. Planting depth and soil texture emergence data were unsuccessfully transformed for ANOVA; thus, a Kruskal-Wallis one-way ANOVA was used for data analysis. Data from wildland harvesting and seed cleaning tests were not analyzed statistically.

RESULTS AND DISCUSSION

Wildland seed harvest
Harvesting bristly fiddleneck via stem cutting from the roughly 3x10 m (10x30 ft) stand at Rock Creek for 60 minutes yielded 8 large paper grocery sacks full of material. Harvest and cleaning activities resulted in a fair amount of skin and eye irritation from airborne bristles. After cleaning, the harvested material yielded 160 g (0.35 lb) of clean seed. Stem cutting is inefficient on a *potential seeds-per-plant* basis. In comparison, two racquet and hopper harvests, one week apart at 10 minutes each (20 minutes total) yielded a total of 240 g (0.52 lb) of clean seed. Raquet and hopper harvests were easier to clean because very little stem material was present. However, because the method is more indiscriminate than stem clipping, it resulted in more collected weed seeds.

These harvest comparisons were done from distinct but visually similar stands. Both sites had very dense, solid stands of robust fiddleneck, 0.3 to 0.6 m (1 to 2 ft) tall, with some interspersed weeds. Yields are reported as suggestions of what could be expected from wildland harvest but stand size, plant productivity, and plant density will vary from site to site.

Seed cleaning
The cleaning techniques used resulted in bristly fiddleneck seed lots with an average purity of approximately 95% with the remainder being mostly inert material (stems and chaff). Seed from the Baker City, OR population averaged 542,000 seeds/kg (246,000 seeds/lb), and seed from Curlew National Grassland, ID averaged 596,000 seeds/kg (271,000 seeds/lb). The overall average for both populations was 570,000 seeds/kg (259,000 seeds/lb).

We similarly achieved excellent purity (>95%) from our single collection of flatspine stickseed. The average seed weight was 133,465 seeds/kg (294,323 seeds/lb).

Fiddleneck germination
We saw significant differences in FG between bristly fiddleneck germination treatments ($P < 0.0001$) (Figure 11). The highest observed FG (93%) was achieved by the Bubbler 18/10C treatment. Significantly greater FG was observed in the bubbler treatments compared to the blotter treatments at 18/10 °C and 22 °C. The Bubbler18C treatment resulted in a 55% increase in FG over Blotter18C+Blch, and FG in the Bubbler22C treatment was 170% greater than seed in the

Blotter22C treatment.

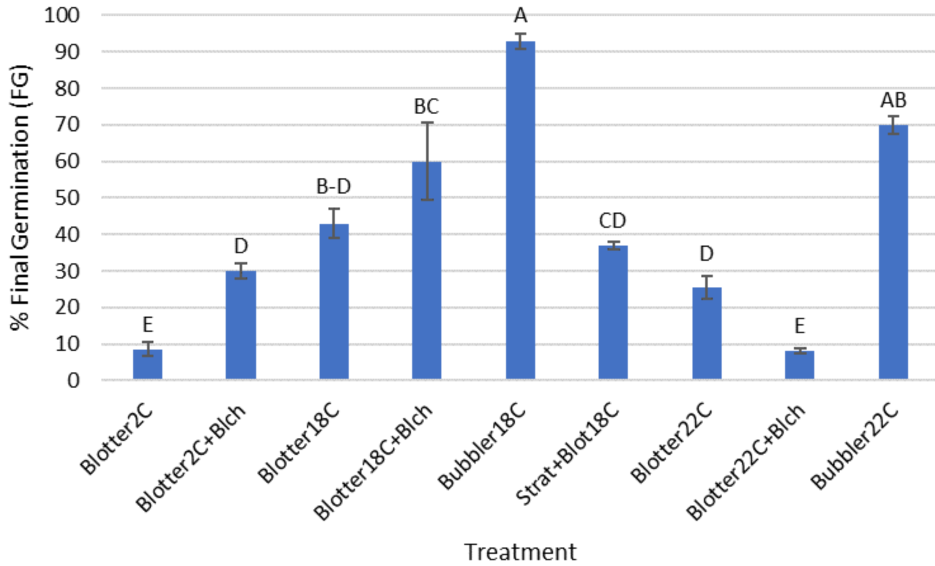

Figure 11. Percent final germination (FG) of bristly fiddleneck seedlings after 4 weeks in 2 growing media (blotter and bubbler) and 3 temperatures (2, 18/10, and 22 °C). Error bars are ±1 standard error of the mean. Different letters indicate significant differences in mean percent emergence at $p < 0.05$.

Germination conditions had a significant effect on the germination of bristly fiddleneck. FG from the Bubbler18/10C treatment was 33% greater than seed germinated at 22 °C in the same environment, though the difference was not statistically significant. However, in the blotter environment, seed germination at 18/10 °C was significantly greater than at 22 °C (60% and 26%, respectively). We also observed low FG of seed at 2 °C (30% with a bleach pre-treatment and 8.5% without bleach).

The addition of a bleach pre-treatment had mixed results. Bleach significantly improved germination of seed grown at 2 °C by nearly 3-fold. Germination was higher in the Blotter18/10C+Blch treatment compared to no bleach treatment, though not significantly so. The bleach treatment followed by 22 °C germination environment resulted in significantly lower germination than non-bleached seed.

Previous reports indicated that stratification was needed to germinate recently harvested bristly fiddleneck seed (Ray and Chisaki, 1957). Seed used in these trials had been in storage for 1 year and may have satisfied that requirement. In this experiment, the FG of stratified seed germinated at 18 °C (37%) did not differ significantly compared to non-stratified seed (43%).

Our results indicate that bristly fiddleneck prefers cool moist conditions for germination with some seeds able to germinate at extremely cold temperatures. Additionally, seeds undergoing 2 °C cold/moist stratification germinated upon removal from the cooler. This may be welcome news for restorationists pitting native forbs against cheatgrass and other cold-germinating invasives. Cold-moist stratification was found to be unnecessary in these trials. Germination of non-stratified seed in blotter and bubbler environments was detected in less than 24 hours. Very quick germination and emergence may contribute to this species' competitive advantage against invasives like cheatgrass and red brome (Abella et al., 2011; Leger et al., 2014). The high germination percentage of 93% suggests that the cleaning protocol used, especially the use of the air column to remove light, non-viable seed, was adequate.

Stickseed germination
The bubbler treatment at room temperature yielded 86% FG of flatspine stickseed. Germination began 3 days after initiation, while peak germination was achieved on day 13. No germinants (0%) were observed in the germination boxes treatment after 13 days. Adding a bleach treatment to blotter germinated flatspine stickseed seed did not result in FG reaching levels obtained in the bubbler. Circulating aerated water may provide enough agitation and water flow to wash the seed coat and prevent spores from adhering. This may account for at least some of the increase in FG.

Improved germination of both species in the bubbler environment suggests that aerated water aids in overcoming seed dormancy. These experiments add two more species to the list of those known to exhibit improved germination in bubblers compared to a standard blotter paper medium (see Tilley and Pickett 2021; Tilley 2013). Higher germination rates and faster, more uniform germination are useful for seed viability testing, greenhouse experiments, and containerized production (Tilley and Picket, 2021). Bubblers could also be used for synchronized production or as a quick means to assess seed viability.

Emergence
No significant difference ($P = 0.1567$) was detected in FG of bristly fiddleneck by soil texture (Figure 12). Nor did we detect a significant interaction factor between soil texture and seeding depth ($P = 0.4035$). Significant differences, however, were observed between soil depths ($P < 0.0001$). Shallow seed placement (0 cm) resulted in significantly better FG and CG for all soil textures compared to 1 and 2 cm depths. Germination at 1 and 2 cm did not differ from each other. After 42 days, very few seedlings had emerged from deeper planting depths (Figure 13). This may indicate a possible light requirement for germination confirming Forbis (2010), or it may be the result of low seedling vigor. For field and restoration purposes, we recommend surface or very shallow seeding depths.

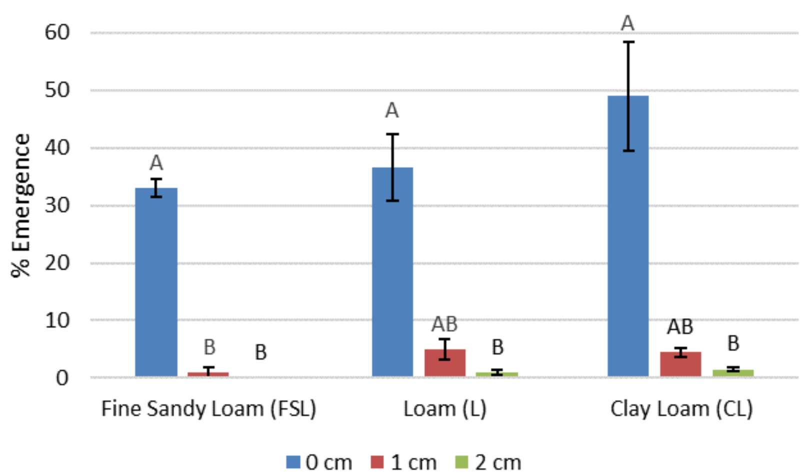

Figure 12. Percent emergence of bristly fiddleneck seedlings after 6 weeks planted at 0, 1, and 2 cm depth in 3 soil textures: fine sandy loam (FSL), loam (L), and clay loam (CL). Error bars are ±1 standard error of the mean. Different letters indicate significant differences in mean percent emergence at p < 0.05 within soil texture groups.

Figure 13. Significantly more seedlings emerged from surface seeding (0 cm). We observed no significant difference in emergence based on soil texture. Photo by Derek Tilley.

This experiment only evaluated germination in three soil textures. Long-term indicators of adaptation such as growth, biomass production, and seed production might be affected by soil texture but were not captured in this study.

CONCLUSION

Our results confirm that bristly fiddleneck readily germinates under laboratory and greenhouse conditions, while flatspine stickseed only responded to the bubbler environment. Quick, synchronized germination of both species is achievable with an aerated water bath (bubbler) environment. We also confirm that bristly fiddleneck, an early seral species, germinates at lower temperatures, supporting the evidence that bristly fiddleneck may have value in recovering disturbed and invaded sites through niche pre-emption (Csákvári et al., 2023) against cool-germinating invasive species. Shallow surface seeding is necessary for seedling emergence, and deeper placement resulted in near-zero seedling emergence. Wildland harvesting of both species is feasible for small amounts of seed, but protective gear is strongly recommended to prevent injury and avoid irritation. Further investigation is needed to determine in-row spacing and plant population density for maximizing seed production. Long-term seed viability testing is also needed to determine shelf storage life and seed banking potential.

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