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Use of Flash Flaming Technology to Improve Seed Handling and Delivery of Winterfat (Krascheninnikovia lanata)

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ABSTRACT

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Ecological restoration of rangelands using wild-collected seeds can be challenging due to low seed quality, inconvenient seed anatomy, and poor plant establishment. In North America, the half-shrub winterfat (*Krascheninnikovia lanata*) is a valuable protein-rich forage for wildlife and livestock. Seeds of this species are contained in one-seeded fruits enclosed in four fluffy, silky bracts. While the seeds can be removed from the bracts, it is not recommended as the bracts are thought to help protect the seed and aid in germination and seedling growth. However, bracts of winterfat make it difficult to incorporate this species within a seed mix because it prevents the seed from flowing through mechanized seeders. The anatomy of winterfat fruit also makes it difficult to treat this species with external seed coating materials that may aid in direct seeding efforts. We tested the use of a recently developed flash flaming technique in combination with seed coating to improve the flowability of winterfat fruits. Our results indicate that flash flaming can reduce the appendages on winterfat fruits, which decreased fruit volume by up to 46% without impacting seed germination. Flash flaming also makes it possible to incorporate a polymer seed coating to the exterior of winterfat fruits. We found that flash flaming combined with seed coating improved the flowability of winterfat fruits, as measured with standard laboratory tests, and by delivering fruits through a broadcast seeder and a rangeland drill. These results indicate that flash flaming plus seed coating provides a new technology that will allow for the treating and planting of winterfat on degraded rangelands.

Keywords: direct seeding, mechanization, flash flaming, *Krascheninnikovia*, restoration, seed cleaning

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TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

In North America, homestead acts (Homestead Act, 1862; Dominion Lands Act, 1872) initiated by the United States and Canadian governments encouraged settlers to expand westward into the interior. These acts allowed for only a relatively small portion of rangelands to be privately owned, with the remaining amount of the land as uncontrolled commons (Bailey et al. 2010; Beschta et al. 2013). Beginning in the 1870's and continuing until the 1930's many investors capitalized on the opportunity to graze on the open rangelands, but did so with stocking rates and management practices that were unsustainable (Monsen & Stevens 2004; Chambers et al. 2007). Excessive grazing on these open rangelands depleted the diversity and overall abundance of many palatable native species (Sayre et al. 2012). Winterfat (*Krascheninnikovia lanata* (Pursh) A. Meeuse & Smit) is an example of a species that has been extensively reduced due to historic over-grazing practices and in more recent decades by annual grass fire cycles, urban development, mining, and other disturbances (Davies et al. 2009; Kitchen & Jorgensen 2001; Emmerich et al. 1993). Winterfat is a long-lived (>50 year) half-shrub (Chambers & Norton 1993) that has an intricate root system to maintain water supply under drought conditions (Booth & Griffith 1984). As indicated by its name, winterfat is a valued forage due to its high crude protein content (>10%) during winter months (Kronberg 2015; Monsen & Stevens 2004). Restoration of this species in degraded rangelands would be of high value for wildlife and livestock due to this species' importance for rangeland forage quality and wildlife habitat (Souther et al. 2019; Carey 1995).

The seed of winterfat is enclosed in bracts that form the utricle (or fruit). The bracts have fine, silky, white, pilose, hairs 3.2-6.4 mm in length on their exterior (Booth & Schuman 1983).

While removing seeds from the utricle through threshing can be beneficial for improved flowability through mechanized seeders, it is not recommended as the threshing process can damage the root cap, and inhibit germination and establishment of seedlings (Booth 1984). However, the fluffy bracts of winterfat make it difficult to incorporate the seed at any significant level within a seed mix because it can prevent the seed from flowing from mechanized seeders. Because of the problematic morphology of winterfat fruits, this species is often not considered a valid candidate for many rangeland restoration projects.

Seed coating technologies can improve handling and sowing of species that are difficult to distribute because of poor flowability within seeding equipment (Pedrini et al. 2020). Applying material to the exterior of the seed (e.g. polymer binders and powder filler materials) can create a more homogenous product that is easier to distribute within a restoration site (Hoose et al. 2019). Our experience at Brigham Young University's Seed Enhancement Laboratory (Provo, Utah, USA) is that it is not practical to coat winterfat fruits using standard seed coating practices. In our attempts to coat winterfat, the fruits tended to conglomerate together into large masses that were too large to plant using standard seed coating equipment.

"Flash flaming" is a recently developed seed cleaning technique that has the potential to improve the delivery of winterfat by reducing the length of the hairs on the fruit's utricle and preparing the surface of the fruit to accept an exogenous seed coating (Ling et al. 2015; Guzzomi et al. 2016). Flash flaming was developed to remove cumbersome hairs, bristles, awns, and other appendages from fruits and seeds that were otherwise unreceptive to conventional seed cleaning techniques. Seeds or fruits are flash flamed by placing the material in a rotary seed coater that has a propane torch positioned close to the rotating stream of seeds/fruits to promote singeing of un-wanted appendages. Through experimentation with the flame torch placement and the length of time the fruits or seeds are subject to the treatment, a user can precisely singe off appendages without impacting seed viability. After applying the flaming treatment, seeds/fruits can also be treated with a polymer seed coating to further improve seed flowability and apply other treatments to enhance seed germination and plant growth (Guzzomi et al. 2016; Erickson et al. 2019). Flash flaming technology has continued to advance with the scale-up of the size of the apparatus used for treating seeds and has been applied to multiple species in Australia and North America (Erickson et al. 2019; Masarei et al. 2021; Berto et al. 2020; Berto et al. 2021).

The objectives of this study were to (1) evaluate if flash flaming could reduce appendages on winterfat fruits and determine the duration the treatment could be applied without impacting seed germination, (2) assess the ability of flash flaming for preparing winterfat fruits to be treated with a polymer seed coating, and (3), quantify the effect that seed coating has on winterfat flowability through laboratory tests and application through mechanized seeding equipment. It was hypothesized that we could find an optimal flash flaming duration that would reduce fruit appendages without significantly impacting seed germination, and this treatment would allow for the application of a polymer coating. We also hypothesized that flash flaming by itself would improve seed flowability but the combination of both flash-flaming and a polymer seed coat would have the greatest improvement is seed flowability and delivery through mechanized seeding equipment.

MATERIALS AND METHODS

Trials were performed at Brigham Young University Seed Enhancement Laboratory on winterfat fruits, obtained from Granite Seed and Erosion Control (Lehi, UT). Between the time of purchase and flaming treatment, the collection was stored in a 4°C cooler in a low humidity environment to maintain seed quality and viability.

Influence of flash-flaming time on fruit volume, mass, and germination

Fruit material was flamed in a 31-cm diameter rotary seed coater (Universal Coating Systems, Independence, OR) with a custom torch-holding attachment that was engineered and installed on the seed coater as described by Guzzomi et al. (2016). We flash-flamed 500 ml (≈ 26 g) of fruits at a time in the rotary coater. During flaming, the rotary coaters pan was operated at 25% of its maximum speed. A propane torch was angled towards the fruits at 45° and approximately 10-15 cm away from the continuous stream of fruits. Prior to flaming the fruits, but while the fruits were in motion, 10 g of water was added directly onto the fruits. While flaming, we added an additional 5 g of water every 60 s. This water was added because our preliminary work indicated that without water the majority of the fruits would combust and subsequently, the treatment would result in lower seed viability. This flash flaming technique was conducted over a range of five flaming durations for 90, 180, 270, 360, and 450 s, to determine the maximum duration fruits could be exposed to flash flaming without impacting seed viability. Each flaming duration was replicated three times. These flame times were evaluated based on their impact on the fruit's volume, mass, and seed germination. To assess flash flaming's influence on fruit volume, we measured the change in volume before and after the treatment in 1,000 ml graduated cylinders. We also measured the change in mass for this same volume of fruits by weighing the fruits before and after treatment to a hundredth of a gram. Germination of the flame treatments was assessed on four replicates in 9-cm diameter Petri dishes. This gave us a total of 12 Petri dishes for each flame duration (i.e., 3 flame replicates x 4 germination replicates). We also included in our germination trial 12 Petri dishes containing unflamed (control) winterfat fruits. Each Petri dish contained 25 fruits dish^{-1} on two layers of blue blotter paper that was moistened with water as needed throughout the study. Petri dishes were incubated at 15°C in a Precision Plant Growth Chamber (Thermo Fischer Scientific, Waltham, MA) with a 12 h light period in a 24-h cycle. Petri dishes were arranged on shelves in the growth chambers in a randomized complete block design with three replicate blocks. Germination was counted every 1-3 d, with the seeds considered germinated when the radicle of the seed had extended 2 mm out of the fruit.

Using the resulting germination data, we estimated the time to 50% germination (T_{50}) and final germination percentage (FGP) for each flame duration and the untreated seed. To accomplish this, we fit three-parameter log-logistic time-to-event models (Ritz et al. 2013). Time-to-event models are well suited for germination timing analysis because they account for analytical challenges characteristic of germination experiments, such as autocorrelation among successive counts, variance heterogeneity, uncertainty surrounding germination timing between counts, and uncertainty surrounding the viability of non-germinated seeds at the end of the experiment (Onofri et al. 2010; Ritz et al. 2013). Time-to-event models thereby produce more robust standard errors around parameter estimates than other approaches (Onofri et al. 2010; Ritz et al. 2013). We performed pairwise comparisons between each flame duration and untreated fruits (i.e., five comparisons) using Bonferroni's adjustment for multiple comparisons. Models were fit using the 'drm' function of the 'drc' package (Ritz et al. 2015) in the R statistical environment (R Core Team 2019).

Influence of seed coating on fruit germination

The flaming duration that reduced fruit volume the most without impacting seed viability was used for seed coating trials, which was a flaming duration of 180 s. The flamed fruits were coated in the same seed coater described previously, with a combination of Agrimer-15 polymer binder (Ashland Inc., Covington, KY) and calcium carbonate (limestone) powder (Clayton Calcium, Parma, ID). In the coating process, 21.5 g of flash-flamed winterfat fruits were placed in the coater at a rotational speed of 25% of the machine's maximum speed. We then applied 25 g of Agrimer-15 at a rate of 2 ml sec^{-1} onto a spinning atomizing disk in the center of the coater that evenly distributed the binder onto the fruits. After the application of the binder, a 60 g burst of limestone powder was added directly onto the rotating fruits. We then added 40 g of Agrimer-15 continuously with a peristaltic pump, and at the same time, 120 g of limestone was added by hand in incremental applications over the same period. Fruits were then coated with an additional 10 g of Agrimer-15 to improve the integrity of the coating and help prevent 'dusting off' of the coating materials. After fruits were coated, they were placed on a forced air dryer (Brace Works Automation and Electric, Lloydminster, SK, CAN) at 43 °C for approximately 20 min.

Under the same methods described in the previous experiment, we measured the change in fruit volume and mass with flash flamed and flash flamed plus a coating treatment (hereafter these treatments will be referred to as flamed and flamed + coated, respectively). We also assessed seed germination T_{50} and FGP of the coated fruits in comparison to flamed fruits and untreated fruits under the same conditions described in the previous germination experiment. This germination study was arranged in the growth chamber in a randomized complete block design with five replicate blocks for each of the three treatments. Each block contained each treatment in separate Petri dishes, with 25 fruits $dish^{-1}$.

Influence of flash flaming and seed coating on seed flowability

We compared the flowability of untreated, flamed, and flamed + coated winterfat fruits by testing their angle of repose and flow through a broadcast seeder and rangeland drill. The angle of repose is a measurement that is used in defining the flow of solid particles that represent a function of interparticulate friction or resistance to movement. We measured the angle of repose on winterfat fruits from a cone-shaped pile of fruits that was made by pouring 1,000 ml of fruits through a 3-cm diameter pipe that was fixed 30 cm above a flat surface. We calculated the angle by taking the inverse tangent of the height of the cone divided by the radius of the base of the cone. This procedure was replicated six times for all three treatments, with the order of the treatment tested randomized.

We directly measured flowability rates of the treatments through a Muratori 500 ITL broadcast seeder (Castelnuovo Rangone, MO) , and a P&F Services rangeland drill (Kemmerer, WY). We attached the broadcast seeder to a John Deere 5520 tractor (John Deere Moline, IL). Each treatment was tested at three different aperture settings (1, 2, and 3) that were marked on the broadcast seeder by the manufacturer. During the experiment, the seeder was run for 30 s while the tractor was held stationary, with the engine operating at 1,700 revolutions per minute (RPM). Each treatment was replicated through each aperture setting three separate times, with the order of the treatment performed randomized. The mass of fruits delivered after 30 s was recorded to allow for a comparison of the different treatments that had different bulk masses. We measured broadcast distance for each treatment, with this data we converted output to kg of PLS $\cdot$ ha^{-1}.

The rangeland drill used for this study had three separate hoppers/boxes and associated seed delivery mechanisms. As named by the company, there is a legume box, for small seeds, grain box, for larger seeds with good flowability, and a fluffy seed box, for seeds with poor flowability. We evaluated flow rates of the winterfat treatments from the grain box and fluffy-seed box. Flowability rates were measured with the rangeland drill elevated on blocks, so that the wheels were free to spin. For the grain box, each seed treatment was replicated through each generic preset opener setting (1-5) six separate times, with the order of the treatments randomized. During each replicate test run, we measured the amount of fruits that were delivered from five complete wheel rotations, which is equal to the drill being pulled 20.7 m. Flowability from the fluffy seed box is based on the speed an auger rotates and pulls seed out of the hopper. The speed of delivery for the fluffy seed box has five different rates, which is set by moving a chain to one of five different size gears. We evaluated each of these five flow rates using the same methodologies as described above. The mass of the delivered fruit from the grain box and the fluffy-seed box was converted to kg of PLS ha^{-1}.

Statistics were performed using JMP®, version 13 (SAS Institute Inc., Cary, NC). We tested for differences in volume, mass reduction and changes in bulk density, as well as differences in flow rates in all flowability trials using a one-way analysis of variance (ANOVA). When the ANOVA null hypothesis was rejected a Tukey HSD pairwise comparison test was performed. Non-transformed data are shown in figures and tables. A significance level of $P < 0.05$ was used; values in table are reported as mean ± standard error (SE).

RESULTS

Influence of flash-flaming time on seed germination, volume, and mass

Winterfat final germination percentage (FGP) was unaffected by flash flaming when the treatment was applied for 180 s or less ($P > 0.05$; Figure 1). In general, FGP of winterfat fruits declined when flash flaming was applied for 270 s or more. At 270 s, FGP declined by 22.4 % ($P = 0.001$) in comparison to unflamed fruits (untreated = 68.9 % ± 4.2, flamed at 270 s = 46.5 % ± 4.5). At flame times of 360 and 450 s, FGP declined by 64.8 % ($P < 0.001$) and 58.0 % ($P <$

0.001) in comparison to unflamed fruits, respectively (flamed at 360 s = 4.2 % ± 1.8, 450 s = 10.9 % ± 3.5). In general, the different flash flaming treatments had similar T_{50} values in comparison to untreated fruits (T_{50} range from 2.2 - 4.1 d). An exception to this was found at the 360 s flash flame time, where germination timing was delayed by 1.7 ± 0.6 d compared to untreated fruits (Figure 2; $P = 0.019$).

Fruit volume and mass declined while bulk density increased with increasing flash flaming time up to 360 s (Figure 2). There was no change in these metrics between 360 and 450 s flame durations (Figure 2). For the 180 s flash flame time, which was the longest flash flaming duration that did not impact FGP, winterfat fruit volume and mass were reduced by 44 and 19 %, respectively (Figure 2). Also, flash flaming winterfat fruit for 180 s increased bulk density by 30%.

Influence of seed coating on seed germination and fruit mass

In our second germination experiment, there was no difference in FGP ($P > 0.05$) and T_{50} ($P > 0.05$) between winterfat fruits that were either left untreated, flash flamed (for 180s), or flash flamed + coated (data not shown). Bulk density of winterfat fruits was increased by 54 and 91 % for flash flamed and flash flamed + coated, respectively (bulk density of flash flamed fruits = 0.053 ± 0.02 g cm^{-3}, flamed + coated = 0.31 ± 0.01 g cm^{-3}).

Influence of flash flaming and seed coating on seed flowability

Flash flaming had a small improvement in winterfat fruit flowability, as measured by the angle of repose test (untreated seed = 45.8 (º), flash flamed = 43.0 (º); Figure 3). This decline in the angle of repose from flash flaming elevated the material from a flowability rating of "Poor" to a "Fair/Passable" classification (Al-Hashemi & Al-Amoundi 2018). Flowability of winterfat fruits that were flash flamed + coated had a marked decline in the angle of repose, in comparison to untreated and flash flamed fruits (flash flamed + coated = 29.8 (º); Figure 3). With this angle of repose, winterfat fruits with the flash flame + coated treatment would be classified as having Excellent flowability (Figure 3).

Winterfat fruits that were flash flamed +coated exhibited higher flow rates through the broadcast seeder, across all opener settings, compared to flash flamed and untreated fruits (Figure 4a). Only trace amounts of untreated and flash flame treated fruits were delivered at each pre-determined opener setting on the broadcast seeder (≤ 0.02 kg PLS ha^{-1}). Coated fruits were able to flow freely at each opener setting, with opener settings 1, 2, and 3 delivering coated fruits at 2.87 ± 0.10, 15.31 ± 0.21, and 19.74 ± 0.59 kg PLS ha^{-1}, respectively (Figure. 4a). Additionally, fruits that were flash-flamed + coated were able to be broadcast 3.6-fold further than untreated or flash-flamed fruits (broadcast distance for untreated and flamed + coated fruits were 3.4 and 12.2 m, respectively).

Flash flamed fruits with a polymer coating also flowed much better through the rangeland drill's grain box compared to untreated fruits, with nearly a 71,000% increase in delivery. Similar to the broadcast seeder, only trace amounts (≤ 0.02 kg PLS ha^{-1}) of untreated and flash-flamed fruits were delivered across all aperture settings. In contrast, flash-flamed + coated fruits were able to surpass typical pure stand seeding rates (6 kg PLS ha^{-1}) for winterfat, by delivering 14.2, 17.7, and 18.6 kg PLS ha^{-1} through aperture settings 3, 4, and 5, respectively (Figure. 4b).

Flow rates of flash-flamed + coated fruits exhibited much better flow through the rangeland drills fluffy seedbox in comparison to untreated fruits with a 119,500% increase in delivery. Flash flamed + coated fruits surpassed a typical pure stand seeding rate by delivering 23.9, 28.6, and 46.9 kg PLS ha^{-1} through aperture settings 3, 4, and 5, respectively (Figure 4c).

DISCUSSION

Winterfat is a desirable forage species for wildlife and livestock (Kitchen & Jorgensen 2001; Emmerich et al. 1993; Davies et al. 2009); however, from a practical standpoint, it is often excluded from seed mixes due to its fruit anatomy, which impedes its flow through traditional mechanized seeders used on rangelands. Flash flaming has shown promise for improving the handling of grassland species with cumbersome seed appendages (Berto et al. 2020; Ling et al. 2019; Guzzomi et al. 2016). In addition to removing un-wanted appendages to enhance the flowability of fruits, flash flaming in all recorded cases has improved the seed coating potential of the material it has been applied to (Berto et al. 2020; Berto et al. 2021; Erickson et al. 2019; Ling et al. 2019; Guzzomi et al. 2016).

We evaluated how flash flaming and seed coating influenced winterfat fruit morphology, viability, and flowability through laboratory germination trials, an angle of repose test, and flow rates through a broadcast seeder and rangeland drill. As hypothesized, an optimal flash flaming duration was achieved, whereby appendages on winterfat fruits were reduced without significantly impacting seed germination (Figure 1). Flash flaming alone, provided only limited improvement in the flowability of winterfat fruits (Figures 3-6). We confirmed that winterfat fruits that had undergone flash flaming could be coated with no effects on seed germination. Seed coating increased the winterfat fruits' bulk density and hardness, and improved the flowability of the fruit sufficiently for winterfat to be efficiently seeded through a broadcast seeder and rangeland drill, with no bridging or clogging of the seeding equipment (Figures 3 -6).

Although flash flaming and coating winterfat seemingly improved all areas of handling and delivery, there are a few potential limitations related to this technology. By adding a seed coating to winterfat there is potential to increase the weight of bulk fruits for shipping and handling of winterfat. Additionally, the increased cost of flash flaming and coating winterfat fruits is an expense that has the potential to put a strain on already stretched resources. However, because winterfat cannot be seeded in its current form, these extra costs appear to be required to seed this species. Based on the results of this research, flash-flaming in combination with seed coating will likely improve the handling, mixing, and delivery of winterfat seed and reduce clogging of mixers, hoppers and seeding equipment, making winterfat a more viable candidate species for restoration and management projects. Furthermore, seeding rates of treated winterfat seed are likely to be more consistent and reflective of the calibrated seeding rates over rugged terrain (Hoose et al. 2019). Flash-flaming plus a polymer coating on winterfat fruit may also mitigate the cost of seeding winterfat through a broadcast seeder, irrespective of issues associated with clogging. We demonstrated that flamed and coated fruits could be broadcast 3.6 times further than untreated fruits. The larger broadcast swath associated with the treated fruits could mitigate seeding costs by covering more area per unit time, thereby reducing costs associated with labor and the use of seeding equipment (Hoose et al. 2019).

Further research is needed to determine how the treatment of winterfat fruits through flash-flaming and seed coating will influence germination and plant establishment in the field. There is evidence that the long, silky hairs on winterfat fruits aid in their ability to be moved by wind and become adhered to the soil (Booth & Schuman 1983). Through the process of flash flaming and removing the majority of hairs on the fruit, we are potentially altering an evolutionary benefit to establishment. However, polymer seed coatings have been shown to aid in seed germination in the field by enhancing seed-soil contact (Blunk et al., 2017). By adding a seed coating, we are potentially mitigating the effects of removing the fruit hairs by replicating its ability to adhere to the soil in which it is sown, thus increasing the likelihood of germination.

Applying a seed coating to winterfat not only improves flowability, it opens the door to the potential benefits of applying a seed enhancement during the coating process (Berto et al. 2021; Berto et al. 2020; Erickson et al. 2019; Ling et al. 2019; Guzzomi et al. 2016). Seed coating technology can be combined with beneficial biological and chemical active ingredients, such as surfactants, predator repellants, plant growth regulators, and fungicides, that can aid in the success of seeding restoration projects (Madsen et al. 2016; Pedrini 2020). The active ingredients chosen to include as part of a seed coating can be tailored based on the individual restoration sites' ecological challenges that may limit plant recruitment (Gornish et al. 2019). Chenopods, including winterfat, are limited by pathogenic activity on rangelands (Garvin et al. 2004). This observation was true while we conducted the germination trials for this study in the laboratory; seeds within fruits that did not germinate were commonly overtaken by fungal pathogens.. The application of a fungicidal seed coating may prevent fungal seedling mortality by preventing the fungi from overtaking the sown material during its vulnerable germination and seedling stages of establishment. Further work should be done to identify the fungal microbiome of winterfat and their soils to determine an appropriate fungicide or biocontrol to use in a seed coating (Appendix 1).

Management Implications

In our anecdotal conversations with managers, winterfat is a frustration and is not considered a viable candidate for a restoration species because of difficulties associated with seeding. For example, one noteworthy conversation with a land manager described their method for seeding winterfat as “cutting a hole in the bag and using a rope to drag the bag behind the drill”. Our research provides the catalyst for resuming large-scale restorations of winterfat stands throughout their range. Winterfat has presented a challenge to land managers because while threshing the seed out of the fruit improves flowability, it often damages the seed and results in poor germination. On the other hand, leaving the seeds in the fruit is favorable to higher germination, but it is nearly impossible for land managers to seed the species through seeding equipment. Flash flaming in combination with seed coating allows for the seed to remain in the fruits and gives land managers the option to seed winterfat through standard seeding equipment.

Future work should investigate the efficacy of flash flaming and seed coating on other North American native fruits or seeds that have appendages that impede flowability, such as, galleta (*Hilaria jamesii* Torr.), rubber rabbitbrush (*Ericameria nauseosa* Pallas ex Pursh [G.L. Nesom & Baird]), big bluestem (*Andropogon gerardii* Vitman), little bluestem (*Schizachyrium scoparium* [Michx.] Nash.), Indiangrass (*Sorghastrum nutans* (L.) Nash), bluejoint (*Calamagrostis canadensis* (Michx.) P. Beauv), spike trisetum (*Trisetum spicatum* (L.) Richter), and many more species from the *Bouteloua* and *Danthonia* genera. Flash flaming in combination with seed coating on these and other similar species has the potential to increase the diversity of seed mixes used by land managers. Increasing species diversity has the potential to improve forage quality on restoration sites; this is especially true for winterfat because of its high palatability for livestock and wildlife, and high protein content during winter months (Kitchen & Jorgensen 2001; Emmerich et al. 1993; Davies et al. 2009).

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FIGURES

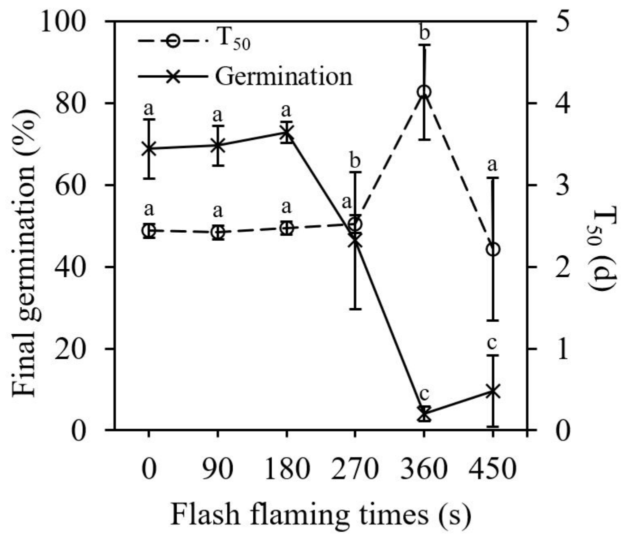

Figure 1. Changes in volume, mass and bulk density for winterfat seeds that had undergone flash flaming from 0 – 450 s

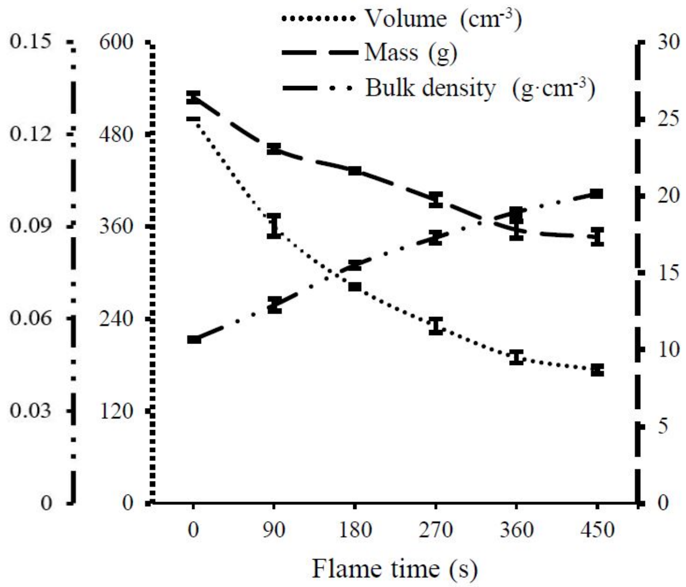

Figure 2. T50 and final germination percentage (%) of winterfat seeds that had undergone flash flaming durations 0 – 450 s.

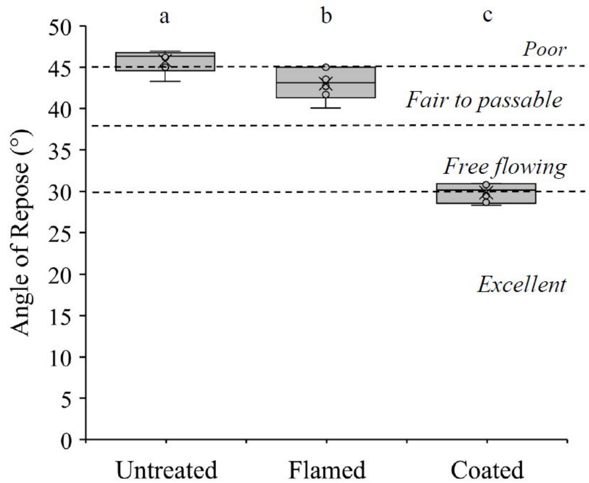

Figure 3. Comparison of angle of repose (AoR) between untreated, flash flamed, and flamed + coated winterfat seeds. Flowability classifications "Poor – Excellent" were established in Al-Hashemi and Al-Amoudi 2018).

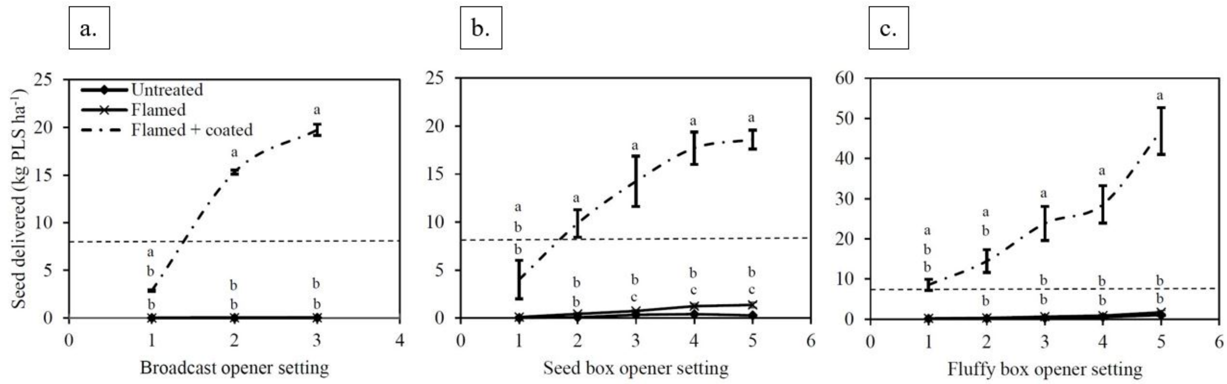

Figure 4. Comparison of flowability rates of untreated, flash flamed and flash flamed with a seed coating through A) rangeland broadcast seeder, B) seed box of a rangeland drill, and C) fluffy seed box of a rangeland drill . Dashed line represents the typical pure stand seeding rate for winterfat through a broadcast seeder (8 kg PLS ha-1).

SUPPLEMENTAL MATERIAL

INTRODUCTION

Winterfat (*Krasheninnikovia lanata* (Pursh) A Meeuse & Smit) is a native species that has been extensively reduced due to abusive grazing practices and other disturbances such as wildfire (Kitchen and Jorgensen 2001). Winterfat is a long-lived (>50 years) half-shrub (Chambers and Norton 1993), which has an intricate root system to maintain water supply and build site resilience against drought (Booth et al. 1984). As indicated by its name, winterfat is a valued forage for wildlife and livestock due to its high (>10%) crude protein content during winter months (Kronberg 2015; Richards and Monsen 2004).

Despite its value on rangelands, winterfat has been underutilized in restorative seeding efforts. Winterfat seed is enclosed in bracts that form a utricle, these bracts are covered in fine, silky, pilose hairs on their exterior (Booth and Schuman 1983). The appendages on the bract impede winterfat fruits from moving through mechanical seeders. Guzzomi et al. (2016) developed a seed cleaning technique that uses “flash flaming” to remove seed appendages. This approach incorporates a propane torch in a rotary seed coater that singes the seeds with a flame while they are rotating within the seed coater. Because the seeds are only in contact with the flame for a brief period, the seed's internal temperature is not raised to a degree where it influences seed viability. In this Thesis we successfully applied the techniques described by Guzzomi et al. 2016 to winterfat fuits, which reduced the length of the appendages on the fruit and allowed for the application of a polymer coating. We also demonstrated how coated winterfat fruits could be delivered successfully through a broadcast seeder or rangeland drill at any desired seeding rate.

In addition to improving seed delivery, flash flaming combined with seed coating provides an opportunity to apply enhancements to the seed that can improve seeding success (Madsen et al. 2016). Regeneration of shrubs from the chenopod family in the Great Basin, including winterfat, is limited by pathogenic activity, which decreases seedling survival (Garvin et al. 2004). Even after flash flaming, it has been our observation that the appendages on winterfat fuits appear to create an environment that promote pathogenic fungi colonization.

There has been limited research within natural systems on seed microbiome origins, routes of colonization ecology and their associated impacts on plant recruitment through direct seeding efforts. For our purposes, seed microbiomes can be simplified into two categories: endophytic microbiota and epiphytic microbiota. Endophytic microbiota are microbial species that reside in internal seed tissues and are vertically-transmitted to progeny seedlings. Epiphytic microbiota, colonize seed surfaces and may or may not become internalized within seed tissues and transmitted either vertically or horizontally. In addition to being present in seeds, many of these fungal genera are commonly associated with soils where they are frequently transmitted horizontally to plants. Recent studies have demonstrated that local site conditions and not host genotype have a strong influence on the assembly of fungal seed microbiomes. We designed a study to be implemented by future researchers to identify the fungal microbiome of winterfat fruits and better determine the origin and colonization winterfat by pathogens. This information could be utilized to formulate seed enhancements, such as a seed coating that incorporate fungicides to prevent pathogen caused mortality to winterfat seeds.

METHODS

Seed and Soil Collection

Winterfat seeds and soil samples will be collected from fourteen sites throughout the Great Basin region of North America, including, Oregon, Arizona, Nevada, and Utah. At each site, seeds will be taken from roughly 50 adult winterfat plants to create a representative sample of the site. At each site samples will be taken randomly from 5 locations within the perimeter where fruits were being sampled. At each site, location the site will be recorded using a handheld Global Positioning System (GPS) in the NAD83 datum.

qPCR Analysis of Seeds and Soil Samples

All seed and soil samples will be tested by Europhins Scientific (Henderson, NV. U.S.A) to determine fungal and bacterial DNA extraction through qPCR methods. qPCR DNA testing will be used to identify an appropriate rate, and formulation of fungicides to be included in a seed coating.

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