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Effects of Planting Date, Harvest Date, and Environmental Conditions on Germination of Forage Kochia Accessions

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EFFECTS OF PLANTING DATE, HARVEST DATE, AND ENVIRONMENTAL CONDITIONS ON GERMINATION OF FORAGE KOCHIA ACCESSIONS

by

Cody F. Creech

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Plant Science

Approved:

Corey V. Ransom Major Professor	Blair L. Waldron Committee Member
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UTAH STATE UNIVERSITY
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ABSTRACT

Effects of Planting Date, Harvest Date, and Environmental Conditions on Germination of Forage Kochia Accessions

by

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Utah State University, 2012

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Forage kochia (*Bassia prostrata*, [L.] A. J. Scott) (Synonym = *Kochia prostrata* [L.] Schrad.) is a perennial semi-shrub that is valued for its forage quality and ability to restore degraded rangeland. However, establishment success of forage kochia plantings in western North America has been erratic. These failures leave the land vulnerable to erosion and invasion of undesirable plants. This research focused on the germination dynamics of forage kochia accessions as it relates to harvest date, planting date, age of seed, and environmental conditions. The effect of planting date, age of seed, and environmental conditions on forage kochia germination was elucidated by planting recently harvested (2010) and year-old, cold-stored seed (2009) monthly, during a four-month period at two locations. Two entries were tested, Immigrant, the standard subspecies *virescens* cultivar, and an experimental line, Sahsel, of subspecies *grisea*. Regardless of planting date, location, or age of seed, Sahsel exhibited higher germination percentages than Immigrant. The age of the seed lots used also significantly affected ($P<0.05$) the germination percentage. Field germination averaged over location and planting date of year-old Immigrant seed was 89.5% less than the current-year fresh seed, and similarly year-old Sahsel seed had 83.6% less germination than current-year seed. Although the two locations were subjected to very different weather patterns, the germination percentage of seeds at each location was not significantly different ($P=0.3156$). In the year we conducted our study (2011), the germination percentage from planting in February was significantly higher ($P<0.05$) than January, which was significantly higher ($P<0.05$) than both March and April. In the final set of trials, different harvest dates were tested by collecting seed in October, November, and December from seven forage kochia accessions. Measurements for total seed yield, 100-seed weight, and germination were collected from seed harvested each month. The month of harvest, accession, and month × accession interaction were significant ($P<0.05$) for each measurement in the study. Two accessions, Pustsel and KZ6Xsel, matured the earliest and had peak seed production at the October harvest (15.1 and 13.4 g plant^{-1}, respectively). The remaining accessions had maximum yield and viable seed from the November harvest.

(86 pages)

PUBLIC ABSTRACT

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Forage kochia is used to re-seed areas in harsh environments that have been infested by annual weeds or disturbed by repetitive fires. It is an introduced perennial semi-shrub that is valuable to livestock and wildlife as a forage. The seed of forage kochia is very unpredictable and successful establishment in areas of low precipitation where it is utilized has often been erratic. Forage kochia seeding failures are costly and leave the land vulnerable to further degradation and erosion. This study was conducted to investigate how germination of forage kochia is affected by different harvest and planting dates, age of seed, type of forage kochia, and weather. This information will be useful to increase the understanding of the germination characteristics of forage kochia and hopefully increase successful plantings.

Results from this study show that successful establishment of forage kochia is affected by many factors related to seed maturity, viability, and the environment required for germination. Harvesting before the seed is mature decreases seed viability. Using fresh, recently harvested seed, as opposed to cold-stored year-old seed for planting, increases the probability of establishment significantly. Gray type forage kochia has larger seed and germinates at higher rates than green type forage kochia. Besides using quality seed, this study demonstrated that planting early in January and February, when cooler temperatures and moisture are prevalent, resulted in the highest germination. Harvesting seed soon after it matures and planting fresh seed early when conditions are favorable will result in improved success of forage kochia plantings.

Dedicated to my beautiful wife, Natalie, for encouraging
me to continue my education and to do my best.

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Cody F. Creech

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CHAPTER 1

LITERATURE REVIEW

Classification and History

Bassia prostrata [L.] A.J. Scott (synonyms = *Kochia prostrata* [L.] Schrad. and prostrate summer cypress) is commonly referred to as forage kochia. It is a member of the Chenopodiaceae or Goosefoot family, which also includes some species that are common and beneficial on western rangeland such as winterfat (*Eurotia*) and saltbush (*Atriplex*). Six species of kochia are commonly found in the United States and only two are native. *Kochia americana* (grey molly) and *Kochia californica* (red molly) are perennial half-shrubs and are native. *Kochia alata*, *Kochia trychophylla* and *Kochia scoparia* are all annual introduced forbs (Shetler and Skog, 1978). Forage Kochia is a perennial semi-evergreen half-shrub that has been seeded on over 202,000 ha in at least 11 western states (Gray, 2011). It is native to arid and semiarid regions of central Eurasia where it is a valuable forage for grazing animals of the region (Balyan, 1972). Two subspecies are commonly recognized in ssp. *virescens* (Frenzl) Prat., a green type forage kochia, and ssp. *grisea* Prat., a gray type forage kochia (Balyan, 1972). Several accessions have been collected and admitted to the United States for evaluation. The first collection was in 1961, with subsequent collections occurring in 1966, 1969, 1971, 1992, 1999, and 2003 (Asay and Johnson, 1992; Clements et al., 1997; Waldron et al., 2001; Waldron et al., 2005). Plants from these seed collections were tested to elucidate their potential as a forage and for use in reclamation projects on western rangelands (Keller and Bleak, 1974; Stevens et al., 1985). Evaluations were conducted in multiple states under differing environmental conditions and in March of 1984 the cultivar Immigrant was released (Stevens et al., 1985). Immigrant, of the subspecies *virescens*, was selected for its attributes as a palatable forage that enhances rangelands and for reclamation purposes through its ability to establish and persist to reduce soil erosion on disturbed sites in the Intermountain West (Harrison et al., 2000). It is adept to inhabit alkaline, stony, and sandy steppes located in deserts, plains, or higher elevations (490 to 2,200 m) (McArthur et al., 1974; USDA NRCS, 2012).

Morphology and Physiology

Forage kochia is a deep taprooted perennial with roots reaching depths over 4 m and lateral roots stretching up to 160 cm (Kashkarov and Balyan, 1989). It is well adapted to rangelands receiving 15 to 40 cm of annual precipitation (USDA NRCS, 2012). A low woody base develops as the plant matures and most of the above ground annual biomass originates as stems from the base (Romo and Haferkamp, 1988). Leaves are narrow, 5 to 20 mm long, covered with a fine pubescence, and remain green late into the year. Generally the lower 1/3 of the plant maintains leaves while the upper stems turn reddish brown and dry up after seed shatter (Stevens et al., 1984). Immigrant can grow as tall as 70 cm and some experimental lines can grow as tall as 120 cm. It may live up to 10 to 15 years and readily reestablishes from seed (Balyan, 1972). Flowers are clustered on a spicate to paniculate inflorescence on the upper stems and bloom indeterminately in the late summer and fall (Harrison et al., 2000). Balyan (1972) suggested that forage kochia is wind pollinated; however, the mode of reproduction has not been thoroughly studied. Seeds are often called utricles, which are characterized by a pouch that has five small wings that contain an individual seed with approximately 2 mm diameter. Forage kochia produces an abundance of seed and full seed production occurs when plants are about 3 years old (Harrison et al., 2000). Seeds ripen unevenly, even on the same raceme, and maturity of seeds from individual plants may vary up to 30 days (Balyan, 1972). Kashkarov and Balyan (1989) noted that seed ripening begins in late September and is complete by mid-October. Davenport (2005) suggested that in some cases, ripening might not be complete until early December. Ripening is often affected by the weather and freezing temperatures can hasten seed ripening (Harrison et al., 2000). There are approximately 395,000 pure live seeds per pound of seed (Koch and Asay, 2001; Harrison et al., 2000).

Beneficial Uses

Forage kochia is an important plant in its native environment and has proven to be an increasingly important plant in the western United States. It is an important forage in its native habitat and is used heavily by the local livestock consisting mainly of sheep, goats, camels, and horses (Balyan, 1972). Since its initial introduction into the United States, it has been studied extensively to identify beneficial and physiological aspects of the species that can be advantageous for use on the western range. Pendleton et al. (1992) and McArthur et al. (1996) espoused forage kochia for its adaptability to the Intermountain West. The majority of plantings have occurred within the boundaries of the Great Basin. Forage kochia has also been successfully established in the Wyoming Basin, Colorado Plateau, and the Snake River Plains eco-regions (Harrison et al., 2000). Immigrant has proven itself to be valuable in a number of applications across the

Intermountain West including being a valuable forage for livestock and wildlife, increasing biodiversity and habitat on rangelands, and use in the reclamation of disturbed sites (Harrison et al., 2000).

Waldron et al. (2011) recommended forage kochia for increasing nutritional value, carrying capacity, and livestock performance on western rangelands. Increased fall and winter forage quality is achieved when grown on sites dominated by perennial grasses (Stevens and McArthur, 1990; Blauer et al., 1993; Waldron et al., 2010). Davis (1979) evaluated the nutritional qualities of forage kochia and discovered that crude protein was comparable to other rangeland shrub species in the summer and maintained higher levels compared to other shrub species through the winter. Crude protein declined from 14.7% in August to 8.9% in March. Waldron et al. (2001, 2005) acknowledged that differences in palatability among accessions and ecotypes exist. The upper stems have higher *in vitro* digestibility (32.2%) than the lower stems (26.3%) and ranked 24 out of 28 for digestibility among species evaluated as potential winter forage (Welch and Davis, 1984).

Forage kochia has been used extensively to rehabilitate severely disturbed sites which frequently occur in harsh environments where other plant materials have been unable to establish and persist at satisfactory levels. It established and persisted on all treated sites in an experiment conducted in central Utah while having the highest mean cover of all species being evaluated for road-side and roadcut plantings, providing critical soil stabilization (Blauer et al., 1993). It has also been successfully established on processed oil shale, other types of mine spoils, and disturbed mine sites (Ferguson and Frischknecht, 1985; McKell, 1986). Forage kochia has prevented soil erosion, flooding, and stabilized highly disturbed blow out areas (Stevens et al., 1984; Rasmussen et al., 1992). Krylova (1988) found that forage kochia could also be used to stabilize sand dunes.

Forage kochia was originally selected for use in rangeland rehabilitation projects for its ability to establish, compete, and persist with annual weeds. Suppression of invasive alien annual weeds such as downy brome (*Bromus tectorum*), halogeton (*Halogeton glomeratus*), Russian thistle (*Salsola tragus*), and medusahead rye (*Taeniatherum caput-medusae*) is a trait forage kochia has been found to have (Van Epps and McKell, 1983; McArthur et al., 1990; Stevens and McArthur, 1990; Monsen, 1994; Koch and Asay, 2001; Young and Clements, 2004). Forage kochia is highly salt tolerant (Francois, 1976; McFarland et al., 1990) and drought tolerant (Romo and Haferkamp, 1988) and because of these attributes has been able to compete within halogeton infested areas. Stevens and McArthur (1990), for example, performed a seven-year study in which forage kochia was seeded into an area dominated by halogeton. Halogeton is able to gain an advantage and encroach into an existing plant community by accumulating salts from the soil and depositing them on the soil surface when the plant desiccates. Throughout the duration of the study, the number of halogeton plants decreased and forage kochia became the dominant plant in the research plots.

More importantly for the millions of acres of western rangelands in the United States now dominated by the introduced annual weed downy brome, forage kochia has proven to be a competitive adversary to the current infestation (McArthur et al., 1990). Monsen and Turnipseed (1990) found that forage kochia could be established in dense stands of downy brome. Pendleton et al. (1992) and Harrison et al. (2000) concluded that forage kochia has the ability to not only suppress, but eliminate downy brome within forage kochia plantings. Monaco (2004) suggested that the growth of forage kochia in the early spring under very cool temperatures allows it to compete for limited water resources which result in direct competition with downy brome. This finding likely illustrates a vital role in the advantage forage kochia has over other annual weeds because forage kochia is able to sequester resources which limit the ability of annuals to establish.

The invasion of downy brome has increased the frequency of wildfires on western rangelands resulting in vast expanses of landscapes characterized by large infestations of annual weeds species with little native vegetation remaining. Forage kochia is a fire tolerant plant (McArthur et al., 1990) and remains green through the fire season. Forage kochia has been utilized successfully in greenstrips to suppress wildfires on the rangeland (Harrison et al., 2002). Greenstrips are narrow bands of densely planted fire resistant vegetation that stretch across vulnerable rangeland. Widths of greenstrips vary from 60 to 120 meters depending on the surrounding fuel load and seeding method. Studies have shown that flame intensity is reduced and some wildfires are even stopped when forage kochia is present (Harrison et al., 2002). Forage kochia can also be seeded in association with crested wheatgrass (*Agropyron cristatum*) as both these species were reported to be the most promising for use in greenstrips on arid lands (Monsen, 1994). The fuel moisture content of forage kochia was estimated at 40 percent, crested wheatgrass at 10 percent, and 1 percent for downy brome (Pellant, 1994). Forage kochia will burn when surrounded by sufficient fuel but quickly recovers (Kitchen and Monsen, 2008). Forage kochia can be an important resource to break the current cycle of frequent wildfires and allow perennial shrubs and grasses the opportunity to establish. Clements et al. (1997)

observed big sagebrush seedlings establishing in stands of forage kochia where downy brome had been suppressed by the forage kochia.

Germination and Establishment

Since the introduction of forage kochia plantings in western North America, establishment success from seedings has been mixed, with both successes and failures. Seeding failures are costly and leave the land vulnerable to erosion and invasion of undesirable plants (Haferkamp et al., 1990). Germination studies conducted to understand the physiology of forage kochia have been restricted to seed obtained from experimental plants which were planted from seed taken from the original collections of forage kochia from its native habitat (Waller et al., 1983). There are numerous factors that have been found that affect the viability and subsequent germination of forage kochia seed. These include harvest date, storage techniques, seed age, and planting date (Kitchen and Monsen, 2001; Stewart et al., 1999; Waller et al., 1983).

Forage kochia seed is harvested in the late fall and usually is planted in the winter or spring (Haferkamp et al., 1990; Monsen and Kitchen, 1994). The small seeds of forage kochia contain limited stored reserves and must be planted on or near the soil surface (Balyan, 1972). This exposes the seeds to fluctuating climatic conditions, particularly soil moisture and temperatures (Evans and Young, 1972; Roundy et al., 1984). The variability of these climatic conditions can negatively or positively influence forage kochia establishment.

In trials conducted in an area dominated by downy brome in Skull Valley, Utah, Page et al. (1994) tested seedbed preparation, seeding methods and rates, and season of planting for forage kochia establishment. Cultivation using a spring tooth harrow, spike tooth harrow, and a control with no preparation was used for the seedbed treatments. Seed was broadcast and drilled in November, December, and February using rates of 1.12 $kg \cdot ha^{-1}$ (1 $lb \cdot ac^{-1}$) 3.36 $kg \cdot ha^{-1}$ (3 $lb \cdot ac^{-1}$) and 6.73 $kg \cdot ha^{-1}$ (6 $lb \cdot ac^{-1}$). Forage kochia establishment was maximized by broadcasting in December using either seedbed preparation treatment which disturbed the soil.

The period of seed ripening of different subspecies of forage kochia are not equal (Balyan, 1972). Seed ripening begins in late September and is complete by mid-October (Kashkarov and Balyan, 1989). Moghaddam (1978) suggested forage kochia seeds may not completely ripen until November, while Davenport (2005) noted from personal observations that in some cases ripening might not be complete until early December. Seed also ripens unevenly across individual plants, and will even vary on the same raceme. This delay in maturity of individual seeds on individual plants may vary up to 30 days (Balyan, 1972). Ripening is affected by weather, and freezing temperatures can hasten seed ripening (Harrison et al., 2000). The USDA NRCS Plant Guide (2012) reported that a hard frost is required before seed will mature. Baskin and Baskin (1973) also found that ripening can vary from year to year due to the length of the growing season, soil nutrients, and available soil moisture. This variability of ripening between plants and subspecies often makes selecting a harvest date to maximize seed viability difficult.

Seed producers are faced with the daunting task of harvesting seed late in the year when inclement weather is prevalent in order to maximize seed viability. If harvested too late, rain, snow, or wind cause the seed to shatter and fall on the ground, resulting in yield loss. The pressure to harvest seed before poor weather arrives might not allow the seed to develop germination controls which likely form toward the end of seed development (Waller et al., 1983). Without germination controls, seeds may germinate under unpredictable environmental conditions which could lead to an establishment failure. Stewart et al. (1999) found that aside from ensuring seed viability, seed maturity had little effect on the germination rate when after-ripening had occurred. After-ripening, which occurs over time after the seed is harvested, is a mechanism which releases seed dormancy and promotes germination (Finch-Savage and Leubner-Metzger, 2006). After-ripening of forage kochia seed may occur in as little as a few weeks at room temperature or over a longer period in cold storage (Balyan, 1972; Kitchen and Monsen, 2008). If fully after-ripened seeds are seeded in the fall or winter, they may germinate too quickly in adverse conditions, leading to poor overall stand establishment (Kitchen and Monsen, 2008). The requirements for after-ripening in forage kochia seeds to occur allows for emergence when better conditions for seedling survival are encountered.

There are two known germination timing mechanisms that prevent germination of forage kochia at inappropriate times. The first is dormancy and the second is slow germination rates (Meyer and Monsen, 1991). Dormancy is a delay mechanism in seeds that prevents premature germination in conditions that might be unsuitable for establishment (Meyer and Monsen, 1991). A large portion of freshly harvested forage kochia seed remains dormant until late winter or early spring (Balyan, 1972). Seed dormancy is often associated with species from unpredictable environments (Meyer and Monsen, 1992), which is a common trait among plants in arid rangelands where rainfall tends to be highly variable.

Slow germination rate is also important for seeds of species from unpredictable climate environments. Meyer and Monsen (1991) found that for big sagebrush (*Artemisia tridentata*), a shrub that is common in areas where forage kochia has been established, having a slow germination rate may have been almost as effective as dormancy in preventing premature emergence of seeds. Forage kochia seeds have a delayed and desynchronized germination rate (Monsen and Kitchen, 1994). This allows seed to germinate over time and should allow for some portion of the seeds to germinate when conditions are favorable for seedling survival. Cold temperature (2 °C) germination tests have been useful in studying germination rate and synchronization because they more closely resemble field conditions when seedling emergence is likely to occur (McArthur et al., 1987; Meyer and Monsen, 1991). Differences in germination rate of forage kochia are magnified at these lower temperatures.

Plantings of year-old seed have experienced particularly low establishment success. Haferkamp et al. (1990) had poor stand establishment using year-old seeds and attributed it to a loss in seed vigor or viability. One factor is the short shelf-life of seeds, especially under uncontrolled storage conditions (Balyan, 1972; Jorgensen and Davis, 1984; Keller and Bleak, 1974). Another factor is that forage kochia seeds that have afterripened have a more rapid and synchronized germination rate (Haferkamp et al., 1990; Kitchen and Monsen, 2008). This again may be detrimental when planting year-old seeds as they may germinate under adverse conditions resulting in establishment failure. Preserving dormancy in forage kochia seeds becomes especially important when seeds are stored for use in years following the preferred growing season, which is the growing season after the seed was harvested. Forage kochia seed should be stored at less than 7% moisture, at temperatures below 5 °C, and in water tight containers (Jorgensen and Davis, 1984). Kitchen and Monsen (2001) suggested additional benefits may be gained by storing seed at temperatures below freezing. Haferkamp et al. (1990) also suggested that successful establishment from later planting dates could be improved if the period of moist soil required for germination and seedling development could be extended for several days in the spring. Suggestions were made that this could be accomplished by utilizing soil moisture conservation techniques, such as furrows or mulching.

Research Objectives

The objectives of this thesis studied the effects that harvest date had on seed size and yield from plants within forage kochia accessions. Germination tests were conducted on the harvested seed to determine how the different harvest dates influenced viability within and across accessions. In a separate study also included in this thesis, seed from different accessions representing both *virescens* (green type) and *grisea* (gray type) forage kochia subspecies were planted on different dates using current-year and year-old seed to determine the germination response to these two factors. With the information gathered from these studies, recommendations can be made to improve the probability of successful forage kochia seedling establishment.

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CHAPTER 2

FACTORS INFLUENCING THE GERMINATION OF TWO ACCESSIONS OF FORAGE KOCHIA (*Bassia prostrata* (L.) A. J. Scott)

Abstract Forage kochia is a drought and salt tolerant perennial, semi-shrub native to the arid and semiarid regions of central Eurasia. Since little is understood about the response of forage kochia seed from the time of seeding, to establishment, the effects of accession, planting date, age of seed, and environmental factors were evaluated. The effect of planting date was evaluated using seed lots representing recently harvested (2010) and cold-stored, year-old (2009) seed from a single entry of each forage kochia subspecies *virescens* and *grisea*. Plantings occurred at two locations, once a month, beginning in January and continuing through May, and subsequently were collected every 15 days until 75 days after planting (DAP) to determine the amount of seed that had germinated. The effect of subspecies, planting date, and age of seed all significantly ($P<0.05$) affected forage kochia germination. At 45 DAP, when field germination was at or near maximum, subspecies *grisea* (2010) had field germination of 84, 96, 80, and 28% compared to subspecies *virescens* which had field germination of 59, 55, 27, and 14% for planting dates in January, February, March, and April, respectively. Year-old seed (2009) of both subspecies germinated much lower with field germination of 13, 14, 10 and 7% for subspecies *grisea* and 6, 9, 0, and 0% for subspecies *virescens* for the same planting period of January through April. Seeding in the winter using current-year subspecies *grisea* seed promotes forage kochia germination and increases the likelihood of successful stand establishment.

Introduction

Many western rangelands are highly degraded and many efforts have been made to establish beneficial vegetation on these disturbed sites. Efforts to establish new seedings on semi-arid rangelands have met with varying degrees of success. To increase the likelihood of establishment, plant species adapted to these harsh environments are often naturally equipped with mechanisms to regulate germination (Meyer and Monsen, 1992). Factors associated with germination control include after-ripening, dormancy, slow germination rate, and asynchronous germination (Haferkamp et al., 1990; Meyer and Monsen, 1991, 1992; Stewart et al., 1999). The environmental conditions in which the seed matures, including temperature, soil nutrients and moisture, length of growing season, photoperiod, light quality, length of growing season, and also the position of the seed on the plant may significantly affect germination characteristics (Baskin and Baskin, 1973).

Forage kochia (*Bassia prostrata* (L.) A.J. Scott, synonym = *Kochia prostrata* (L.) Shrad.) is a long-lived, perennial, half-shrub native to central Eurasia, where it is an important plant providing quality forage for sheep, goats, cattle, camels, and horses (Balyan, 1972; Waldron et al., 2010). Forage kochia was first introduced to the United States in the early 1960’s and the cultivar ‘Immigrant’, subspecies *virescens,* was released in 1984 after evaluations identified it as a palatable forage that had exceptional ability to establish, persist and reduce soil erosion on disturbed sites in the Intermountain West (Harrison et al., 2000; Stevens et al., 1985). Immigrant forage kochia has proven to be highly adapted to western U.S. rangelands (Pendleton et al., 1992; McArthur et al., 1996) and has since been planted on over 202,000 ha in the Western U.S. (Gray, 2011).

It has been used extensively to rehabilitate severely disturbed sites in harsh environments where other plant materials have been unable to establish and persist at satisfactory levels (Monaco et al., 2003).

Forage kochia is highly tolerant to salt (Francois, 1976; McFarland et al., 1990) and drought (Romo and Haferkamp, 1988), and competitive against invasive annual weeds, such as downy brome (*Bromus tectorum*), halogeton (*Halogeton glomeratus*), Russian thistle (*Salsola tragus*), and medusahead (*Taeniatherum caput-medusae*) (Van Epps and McKell, 1983; McArthur et al., 1990; Stevens and McArthur, 1990; Monsen 1994; Koch and Asay, 2001; Young and Clements, 2004). Forage kochia is also fire tolerant (McArthur et al., 1990; Harrison et al., 2002), and can be an important resource to break frequent wildfire cycles and allow perennial shrubs and grasses the opportunity to establish (Monaco et al., 2003). Forage kochia has also proven to be a valuable winter forage by increasing nutritional value, carrying capacity, and overall livestock performance when grazed in the fall and winter (Waldron et al., 2006, 2010, 2011). Forage kochia is different from the weed annual kochia (*Kochia scoparia* L.) in that it is a perennial semi-shrub that does not accumulate a seed bank in the soil and will not spread into perennial plant stands (Harrison et al., 2000).

Establishment of forage kochia plantings has proven to be inconsistent in part because of a lack of understanding the biology of forage kochia seeds. Forage kochia seed is harvested in the late fall and is usually planted in the winter or spring (Haferkamp et al., 1990; Monsen and Kitchen, 1994). This makes forage kochia a peculiar C_4 plant (Pyankov et al., 2001) in that it has the ability to germinate when cold temperatures are present. Monaco (2004) suggested that the germination of forage kochia in the early spring under very cool temperatures allows it to sequester valuable resources even before annual weed species start to grow. However, the small seeds of forage kochia contain limited stored reserves and must be planted on or near the soil surface and are often broadcasted over snow (Balyan, 1972). This exposes the seeds to fluctuating climatic conditions, particularly soil moisture and temperatures (Evans and Young, 1972; Roundy et al., 1984).

Two known mechanisms that prevent germination of forage kochia at inappropriate times are dormancy and slow germination rates (Meyer and Monsen, 1991). Seed dormancy, a delay mechanism that prevents premature germination in conditions that might prove to be unsuitable for establishment, is often associated with species from semi-arid rangelands where rainfall tends to be highly variable (Meyer and Monsen, 1992). In forage kochia, a large portion of freshly harvested seed remains dormant until late winter or early spring (Balyan, 1972). After-ripening, which occurs after the seed is harvested and is the method which releases seed dormancy and promotes germination (Finch-Savage and Leubner-Metzger, 2006), may occur in forage kochia in as little as a few weeks at room temperature or over a longer period in cold storage (Balyan, 1972; Kitchen and Monsen, 2008). Prior to after-ripening, forage kochia seeds have delayed and desynchronized germination, which allows for some portion of the seeds to germinate when conditions are favorable for seedling survival (Monsen and Kitchen, 1994). Also, plantings of year-old seed have experienced particularly low establishment success (Haferkamp et al., 1990), which could be from after-ripened forage kochia seed having a more rapid and synchronized germination rate (Haferkamp et al., 1990; Kitchen and Monsen, 2008). Another possible factor of these failed plantings may be the loss of seed viability or vigor, especially under ambient storage conditions (Balyan, 1972; Jorgensen and Davis, 1984; Keller and Bleak, 1974).

Limited research has been conducted on the response of forage kochia seed from the time it is planted until seedling establishment. Seeding failures are costly and leave the land vulnerable to wind and water erosion as well as invasion by undesirable plant species. The objective of this study was to conduct tests in a field setting to elucidate how germination is affected by the factors of planting date, seed age, subspecies, and environmental effects. The results of this study expand the current understanding of the response of forage kochia seed to the environment and can be used to formulate recommendations to improve the probability of successful establishment of forage kochia plantings.

Materials and Methods

Two locations were selected from the Utah Agriculture Experiment Station Research Farms that have different weather patterns. The Blue Creek Research Farm (Latitude and Longitude; 41.9335, -112.438) located approximately 15 miles northwest of Tremonton, Utah, has an elevation of 1,582 m. The Evans Research Farm (Latitude and Longitude; 41.6945, -111.833), Millville, Utah, has an elevation of 1,382 m. Both locations had been rototilled multiple times during the previous year and had very little plant residue remaining on the soil surface. Weather statistics for air temperature and precipitation were recorded hourly by stations located on the farms. Soil surface temperature was recorded on 30 minute intervals by outdoor sensors (4-channel Hobo, Onset Computer Corporation, 470 MacArthur Boulevard, Bourne, MA 02532) that were placed in the field at the first planting. Snow depth was recorded manually every 15 days when plantings and collections would take place.

Four different seed lots from two forage kochia accessions were used for this study. The first, Immigrant (ssp. *virescens*), is one of two commercially available cultivars of forage kochia. The second, Sahsel (ssp. *grisea*), is an experimental population developed by the USDA-ARS and originated from Uzbekistan varieties and collections (Waldron et al., 2005). Immigrant seed for this study was obtained through a commercial source from seed harvested in 2009 and 2010 and represents different lots. Seed from Sahsel was also harvested in 2009 and 2010 from seed increase plots and represents two lots. The seed was air dried and cleaned using common seed cleaning methods. Seed harvested in 2009 represents year-old seed and was cold-stored at 4 °C to preserve viability until it was used in this study. Samples of each seed lot (Immigrant 2009, 2010, and Sahsel 2009, 2010) were sent to the University of Wyoming Seed Analysis Lab to be tetrazolium tested to determine viability. These results were used to determine the percentage of pure live seed of each lot. Based on this percentage, seed from each lot was counted so each replication of each seed lot contained 50 pure live seed (Table 2-1). Seed was counted over a 2-week period for all four planting dates and stored in warehouse conditions with fluctuating temperatures until their planting date.

Two layers of blotter paper (Number 3, Steel Blue Germination Seed Blotters, Anchor Paper Co., Saint Paul, MN), cut into 10 cm × 10 cm squares were placed inside 10 cm × 15 cm white nylon mesh bags (white flat organza, Paper Mart, www.papermart.com). Seeds that had previously been counted were retrieved from storage on the day of planting and arranged on top of the blotter paper inside the nylon mesh bags after which the bags were sealed using an impulse heat sealer (Midwest Pacific MP-8, J.J. Elemer, 1867 Craig Road, St. Louis, MO 63146). The blotter paper, nylon mesh bag, and seeds were collectively referred to as a packet in the research. The blotter paper was to act as a replacement for soil-seed contact by providing a medium which water could be held for the seeds to imbibe in the packet. The packets were then organized by collection date and location. There were a total of four planting dates with packets placed in the field on January 19, February 16, March 16, and April 13 of 2011. January 19 was the earliest freshly harvested current-year seed could be cleaned and made ready, which is typical for forage kochia seed. Seed packets were collected from the field at 15-day intervals after planting (DAP) until 75 DAP for all four plantings.

The packets were arranged in a split-split-plot design (Gomez and Gomez, 1984) with planting date as the whole plots, collection date as the subplot, and seed lot as the sub-subplot. Three replicates were randomized within each planting date/collection date such that seed packets could be retrieved without disturbing the packets designated to be retrieved at subsequent collection dates. The packets were placed flat on the soil surface if no snow was present. If snow was present, the snow was excavated for each block and care was taken to not disturb the soil. Chicken wire was placed over each group of packets and staked down to prevent the packets from moving. If snow was excavated, it was returned after the packets had been positioned to bury the packets. This was done to simulate an individual seed melting through the snow profile. Previous observations from broadcast seedings noted that due to its black color, the seed would melt into the snow.

On the day of collection, three replicates for each seed lot and planting date were retrieved from each location. The packets were placed in a cooler with ice and taken directly to the laboratory for processing. There, packets were removed one at a time and soil and ice were gently washed from each bag before opening. The packets were cut open to allow easy access to evaluate the germination status of the seed while not damaging any that had germinated. A seed was considered germinated when the radicle had extended approximately 5 mm. The seeds that had germinated were removed from the packets and discarded after the total number that germinated had been recorded. This process was completed within 6 hours after the packets were removed from the field. To identify viable seeds that did not germinate under field conditions, non-germinated seeds were removed from the packets and arranged in a germination box (Acrylic Germination Boxes, 11 cm, Cont 156C, Hoffman Manufacturing Co., Albany, OR.) on two layers of blotter paper that had been saturated with deionized water. Prior to closing, each box was treated with two sprays from a spray bottle of a solution of 5 ml of chlorine to 500 ml of water that acted as a fungicide. The lids were placed on the boxes and they were randomly arranged in an incubator at 20 C for seven days. After seven days, the number of germinated seeds was recorded.

All data were analyzed using the Proc Mixed procedure of SAS (Littell et al., 2006) with replication as the random variable. Mean comparisons were made among treatments using Fisher Protected LSD tests at the $P = 0.05$ level of probability (Steel et al., 1997). Data are presented as the mean across both locations as the analyses revealed no significant location main effect or interactions (Table 2-2).

Results and Discussion

Effect of Subspecies

Germination percentage was significantly different ($P<0.05$) among the two accessions in the study (Table 2-3). Regardless of planting date, location, or age of seed, Sahsel, subspecies *grisea*, exhibited higher field germination percentages than Immigrant, subspecies *virescens* (Figure 2-2). Sahsel had the highest average germination (44%) compared to Immigrant (28%) when combining both seed lots (2010, and 2009) for each accession averaged across planting date (Table 2-3). Kitchen and Monsen (2008) concluded germination is highly variable among subspecies. The results from our study confirm a high variability among subspecies and are consistent with the work of Waller et al. (1983) that found subspecies *grisea* had higher germination percentages regardless of harvest date, drying procedure, or storage method used. In Waller et al. (1983), subspecies *grisea* germinated at a much higher rate than subspecies *virescens* in a 30 day germination period. Likewise in our study, the germination percentage of Sahsel was much higher than Immigrant during the initial collections for each planting date confirming that *grisea* germinates at a higher rate than *virescens* (Figure 2-2). The higher rate of germination percentages of Sahsel suggest it may benefit from added stored reserves from having a larger seed size (0.1113g 100-seed^{-1}) that is nearly twice the size of Immigrant seed (0.0755g 100-seed^{-1}) (Chapter 3). This can be especially important as favorable environmental conditions begin to deteriorate in the spring similar to the rising temperature and lack of precipitation that occurred in our study (Table 2-4, Figure 2-1). Forage kochia has limited stored reserves (Balyan, 1972) due to its seed size. This research did not explore other physiological differences between Sahsel and Immigrant.

Therefore, possible causes for differences among these subspecies of forage kochia could also be related to differences in genetics, seed vigor, or effectiveness of germination controls.

Effect of Seed Age

The age of the seed lots also significantly affected ($P<0.05$) the germination percentage. Germination of year-old cold-stored seed (2009) of Immigrant in the field was 89.5% less than the current-year fresh seed (2010) while Sahsel was 83.6% less (Table 2-3). When combining the germination observed in the field with that in the lab, year-old cold-stored seed of Immigrant and Sahsel was 87% and 83% less than the current-year fresh seed, respectively (Table 2-3). As would be expected, as more seed germinated in the field, fewer seeds would germinate in the lab until lab germination was approximately zero by 75 DAP (Figure 2-3). This was the case for both recently harvested and year-old seed suggesting that seeds that were viable at planting either had favorable conditions that promoted germination in the field or lost viability waiting for those conditions to occur. Since tetrazolium tests were conducted on all seed lots to determine the percentage of pure live seed and seed was counted to ensure approximately 50 pure live seed were in each packet, the large difference in germination percentage of the current-year seed and the year-old cold stored seed is therefore, likely related to seed vigor.

Haferkamp et al. (1990) had a reduction in seedling density when comparing fresh and year-old seed used in plantings and suggested loss of seed viability in forage kochia might be accelerated in the field, or seed vigor progressively deteriorates with year-old seed. Bleak (1959) noted that old seed of Tualatin oatgrass (*Danthonia* sp.) with low initial viability lost more viability than newer seed with higher viability when incubated together under snow cover. It is known that seed can be viable and have low vigor which results in low rates of germination (AOSA, 2002). Principle causes of low seed vigor can include any combination of the follow: genetic constitution, environment and nutrition of mother plant, stage of maturity at harvest, seed size and weight, mechanical integrity, deterioration and aging, and pathogens (AOSA, 2002). To preserve viability/vigor of forage kochia, seed should be stored at less than 7% moisture, at temperatures below 5 °C, and in water tight containers (Jorgensen and Davis, 1984). In our study it was unclear if the year-old cold-stored seed lost viability after planting or did not have sufficient vigor to germinate when conditions were favorable. Regardless, recently harvested current-year seed, as long as the seed is viable, has sufficient vigor to germinate at satisfactory levels if planted in conditions that promote germination.

Effect of Planting Date and Environmental Conditions

In the year we conducted our study (2011), planting in January and February resulted in the highest germination rates for Sahsel while planting in January was highest for Immigrant (Figure 2-2). High germination rates in January and February are similar to the findings of Haferkamp et al. (1990) that reported that seedling establishment of Immigrant was improved 85% when planting in December and January when compared to planting in February or March in Oregon. In another experiment conducted in Skull Valley, Utah to determine the best method for establishing forage kochia, Page et al. (1994) tested among other things, time of planting. Using planting dates in November, December, and February, the treatment which forage kochia established the best was in December. Similarly, in our study, planting in January and February resulted in germination nearly twice (35 compared to 19%) that of planting in March and April when combing both accessions and recently harvested and year-old seed. When only comparing recently harvested seed, this difference is even more pronounced with an average germination of 61% in January/February compared to 33% in March/April.

The higher rate of germination found in February when compared to January in our study is likely the result of slightly warmer temperatures combined with adequate moisture (Table 2-4). Although the two locations were subjected to very different weather events, the germination percentage of seeds at each location were not significantly different (P = 0.3156). The Blue Creek Farm was snow covered until late March and received little additional precipitation (Table 2-4). The Evans Farm had only two minor snow storms that did not persist for many days on the soil. However, the Evans Farm did receive more precipitation throughout the study which provided favorable moisture for germination. Although snow cover and precipitation were very different, temperatures were very similar (Figure 2-1). Haferkamp et al. (1990) observed that Immigrant forage kochia germination was enhanced when seed was able to imbibe in cold-moist environments suboptimal for germination. Other plant species have also responded favorably to stratification (Mayer and Poljakoff-Mayber, 1975). Imbibed forage kochia seeds germinate at a more rapid rate when temperatures are elevated when compared to freshly-planted seeds (Haferkamp et al., 1990). Haferkamp et al. (1990) first observed Immigrant seeds germinating in late February when maximum and minimum temperature averaged 7 and -5 °C, respectively. Earlier, Romo and Haferkamp (1987) predicted temperatures of 10 to 20 °C combined with high osmotic potential would yield good germination. Our results suggest that forage kochia will germinate at even colder temperatures (as low as -4 and -1 °C average air and soil surface temperature, respectively) if able to imbibe moisture (Figure 2-1).

The main objective of this research was to expound upon the limited understanding of the response of forage kochia seed from the time it is planted until seedling establishment. Figure 2-2 elucidates how seed actually responds in the field after planting. Field germination response to days after planting (DAP) was highly variable across planting dates (Figure 2-2). For the January planting, due to cold temperatures at both locations (average daily temperature for the 0-30 DAP period was -3 °C) and limited moisture at the Evan's Farm (Table 2-4, Figure 2-1), germination was slow until 30 DAP and then more than doubled at 45 DAP for all seed lots. This is significant because the majority of the total seed that germinated did so within the 15 day period between 30 and 45 DAP (Figure 2-2) (the average daily temperature for the period of 30-45 DAP was -0.5 °C). Forage kochia seed is known to have asynchronous germination prior to after-ripening (Monsen and Kitchen, 1994). Kitchen and Monsen (2001) observed low temperature germination of forage kochia was delayed and asynchronous for recently harvested seed. However, in our study it appeared that a cold period allowed forage kochia seed to overcome the limitations of asynchronous germination promoting the more synchronized germination as observed between 30 and 45 DAP (Figure 2-2). The February planting responded favorably to moisture and temperatures (Table 2-4, Figure 2-1) and most viable seed germinated within 30 DAP and Sahsel distinguishing itself from Immigrant (Figure 2-2). Sahsel (2010) had 67 and 91% germination for 15 and 30 DAP compared to 22 and 49% for Immigrant (2010). This increase in the rate of germination also coincides closely with the average daily soil surface temperature rising above 0 °C (Figure 2-1). In the March planting, Sahsel (2010) showed substantial increases from 15 to 45 DAP with germination percentages of 39, 69, and 80, respectively. In comparison, Immigrant (2010) showed little increase with percentages of 21, 28, and 27 for 15-45 DAP, respectively (Figure2-2). The March planting was subjected to warmer temperatures and snow was entirely absent 10 days after planting at Blue Creek suggesting less moisture was available for germination (Table 2-4). Regardless, Sahsel (2010), possibly due to its larger seed size, responded and was able to achieve 80% germination at 45 DAP. Conditions worsened in April as noted by the lower germination rates of all seed lots (Figure 2-2). Although germination was relatively flat in April, it is worthy to note the slight bump in germination that occurred at 30 DAP for all seed lots in response to significant spring rains that occurred (Table 2-4, Figure 2-2). Peak germination would generally occur at 45 DAP for Sahsel and at 60 DAP for Immigrant reflecting a difference in rate of germination between accessions. Figure 2-2 also show a decline in germination at 60 and 75 DAP that is more pronounced with current-year (2010) seed. This was the result of making germination counts in the spring when temperatures had increased and soil moisture decreased, drying the seedlings inside the packets which caused difficulty in getting an accurate count. Therefore, little relevance should be given to the declining germination counts illustrated at 60 or 75 DAP in Figure 2-2.

In summary, both recently-harvested and year-old cold-stored seed of Sahsel ssp. *grisea* germinated at higher rates than Immigrant, ssp. *virescens*, in the field regardless of planting date, location, or DAP. Planting in the months of January and February resulted in the highest germination for all four seed lots used. Recently harvested seed germinated at much greater rate than year-old seed regardless of planting date, location, or DAP. The pattern of forage kochia germination (Figure 2-2) indicated that seed generally germinates before 45 DAP when seeded in January and February. This verifies that forage kochia germinates in cold temperatures (average daily air and soil surface temperature during this period was -3 and -0.5 °C, respectively). Planting forage kochia in these early months when snow is present or likely also allows forage kochia seed to imbibe moisture at cold temperatures which enhances germination when temperatures are favorable. The risk of forage kochia seed failing to germinate increases substantially when soil is only moist for short periods after rains, and temperatures begin to rise in the spring. Successful establishment of forage kochia from plantings later in the spring can occur if the period of moist soil required for germination can be achieved through spring rains with enough frequency or intensity to allow the soil to remain moist for several days. Planting fresh, recently-harvested seed should be a priority when possible to ensure success. If planting year-old cold-stored seed, germination and vigor tests should be used to determine an appropriate seeding rate. In conclusion, using current-year seed of ssp. *grisea* and planting in the winter months (January and February) promotes the highest rates of germination.

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Table 2-1. Seed count for forage kochia seed lots and corresponding pure live seed (PLS) percentage used to obtain 50 PLS per packet.

Entry	Year†	PLS‡	Count
		%	no. packet-1
Immigrant	2010	53	94
Immigrant	2009	29	172
Sahsel	2010	92	54
Sahsel	2009	15	333

†Year the seed was harvested.

‡Pure live seed percentage determined by tetrazolium test.

Table 2-2. Significance of main and interaction effects of the germination of two accessions of forage kochia. The field germination represents germination that occurred in the field and the lab germination represents germination of seed in the lab that had failed to previously germinate in the field.

	Field Germ	Lab Germ	Total Germ
	P-value		
Location†	0.3156	0.1991	0.7389
Plant Date	<0.0001	<0.0001	<0.0001
Entry	<0.0001	<0.0001	<0.0001
Plant Date × Entry	<0.0001	<0.0001	<0.0001
DAP	<0.0001	<0.0001	<0.0001
Plant Date × DAP	<0.0001	<0.0001	<0.0041
Entry × DAP	<0.0001	<0.0001	<0.0001
Plant Date × Entry × DAP	<0.0001	<0.0001	<0.0003

†Interactions involving location were not included due to a lack of significance.

Table 2-3. Average germination of seed harvested in 2009 or 2010 of two forage kochia accessions. Values represent the average across two locations and four planting dates. The accessions represent ssp. *grisea* (Sahsel) and *virescens* (Immigrant). The field percentage represents germination that occurred in the field and the lab percentage represents germination of seed in the lab that had failed to previously germinate in the field.

Seed lot	Field†	Lab	Total
	%		
Sahsel10	59.8 a	16.0 a	75.1 a
Immigrant10	33.8 b	15.8 a	49.6 b
Sahsel09	9.8 c	2.9 b	12.8 c
Immigrant09	3.6 d	3.0 b	6.5 d

†Values within each category followed by different letters are significantly different at *P*<0.05.

Table 2-4. Snow depth, number of days of snow cover, precipitation, and number of precipitation events at locations used to evaluate the effect of planting date on forage kochia germination.

	Blue Creek Farm				Evans Farm			
	Snow†		Precipitation‡		Snow		Precipitation	
Period	Depth	Days§	Amount	Events	Depth	Days	Amount	Events
	cm	no.	Cm	no.	cm	no.	cm	no.
Jan 15 – Feb 1	33	15	0.0931	3	3	2	0.5842	3
Feb 1 – Feb 15	36	15	0.2286	1	0	0	0.8636	3
Feb 1 – Feb 15	25	15	0.2794	8	13	10	3.2004	7
Mar 1 – Mar 15	20	15	0.2582	6	0	0	2.9972	7
Mar 15 – Apr 1	10	10	0.3651	8	0	0	2.7686	9
Apr 1 – Apr 15	0	0	0.1016	5	0	0	4.7752	7
Apr 15 – May 1	0	0	0.3016	8	0	0	4.9784	7
May 1 – May 15	0	0	1.0583	3	0	0	3.5560	7
May 15 – Jun 1	0	0	0.5870	9	0	0	8.6614	10

†Measurements were taken at the beginning and end of each period. Depth is in cm.

‡Amount was measured in cm as total during that period and events denotes the number of days within the period precipitation was received.

§Value of 15 indicates snow cover was present throughout the entire period.

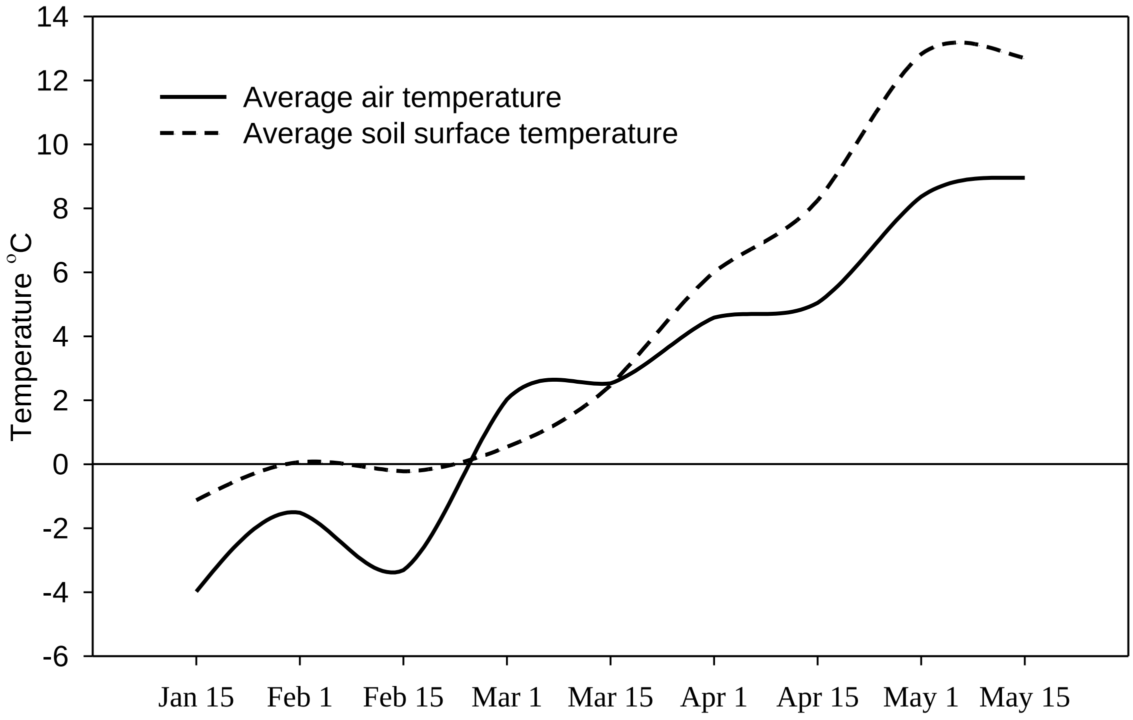

Figure 2-1. Daily average air and soil surface temperature during the duration of forage kochia germination experiments averaged across locations in 2011. Locations for the experiment were at the Evans Research Farm in Millville, Utah and the Blue Creek Research Farm, 15 miles northwest of Tremonton, Utah.

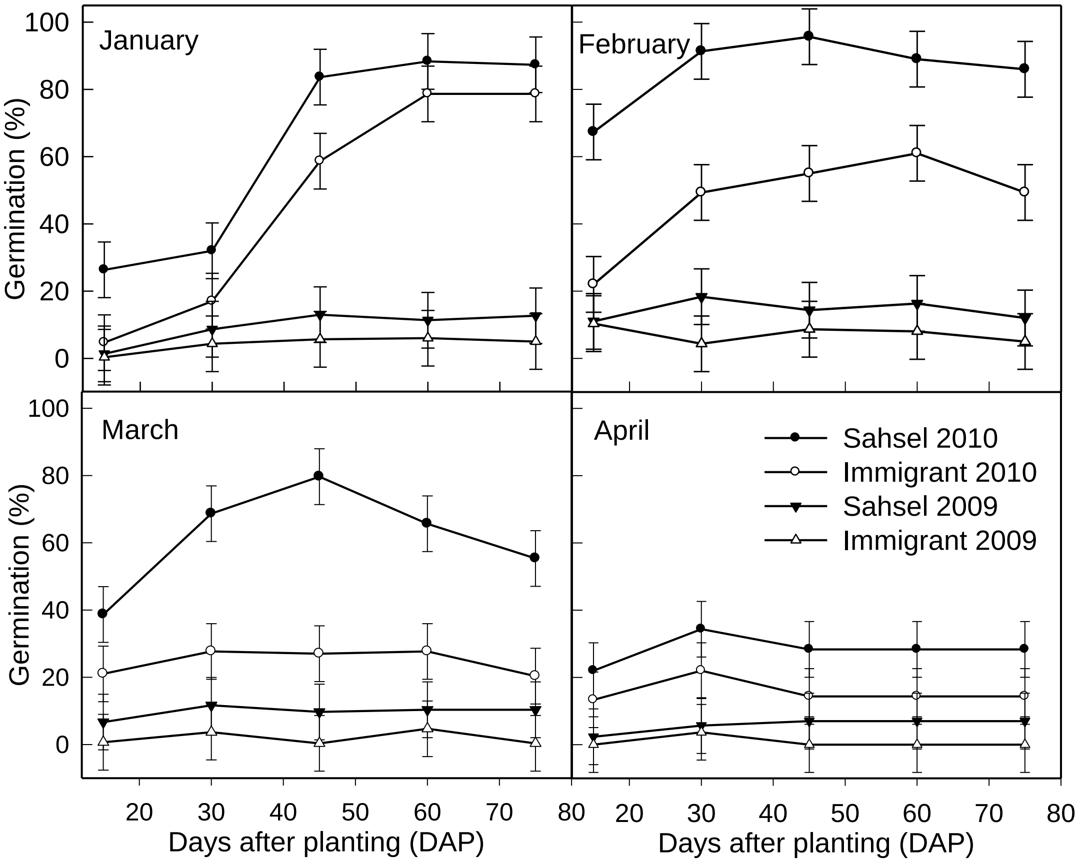

Figure 2-2. Germination response of two accessions of forage kochia (Immigrant ssp. *virescens* and Sahsel ssp. *grisea*) to planting in January, February, March, and April using recently harvested (2010) and year-old cold-stored (2009) seed lots. Symbols represent means (n=6) of data combined from both locations. Whiskers represent a (LSD) of 8.3.

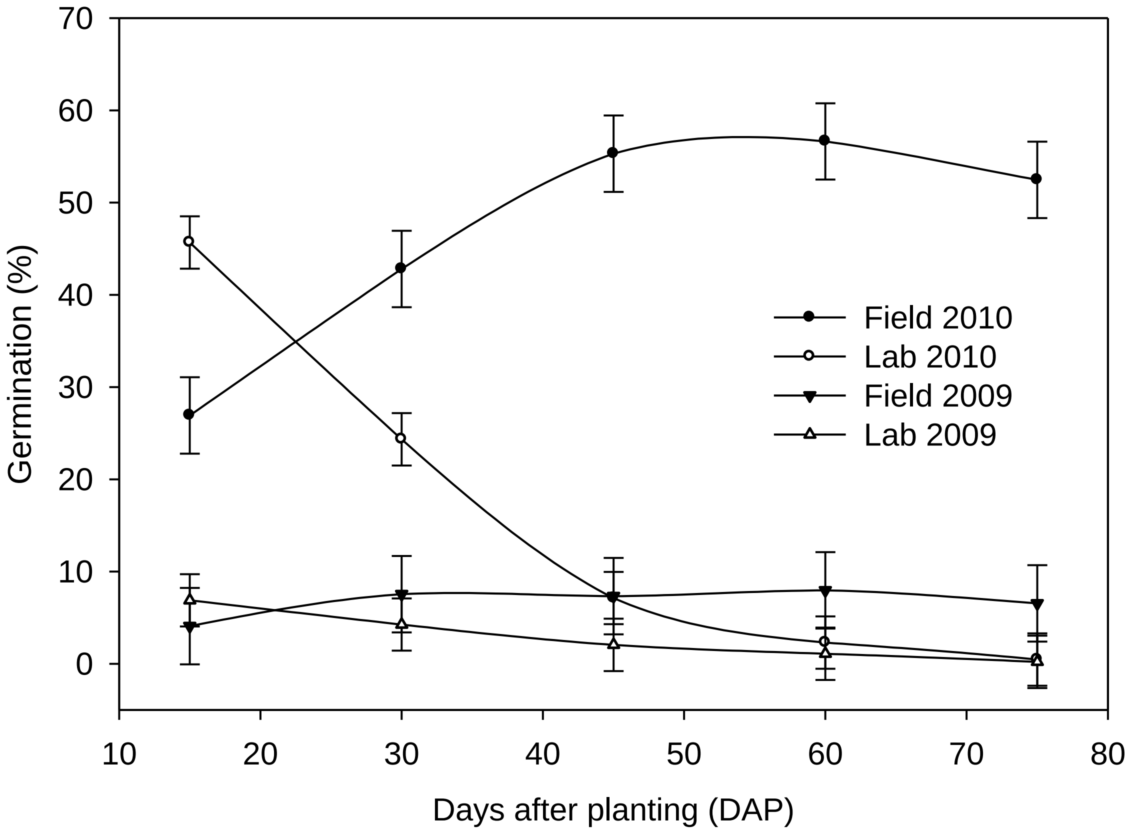

Figure 2-3. Germination percentage of current-year and year-old seed contrasting field and lab germination. Symbols represent means (n=48) of data combined from both locations and averaged over planting dates. Data from both accessions, Immigrant (ssp. *grisea*) and Sahsel (ssp. *virescens*) were combined. Whiskers represent a LSD of 4.1 for field germination and 2.8 for lab germination.

CHAPTER 3

FORAGE KOCHIA (*Bassia prostrata* (L.) A. J. Scott) SEED YIELD AND GERMINATION AS AFFECTED BY HARVEST DATE

Abstract Forage kochia is a semi-evergreen perennial half-shrub native to the arid and semiarid regions of central Eurasia. Introduced into the western United States in the early 1960's, forage kochia has demonstrated its ability to reclaim disturbed sites, compete with annual weeds, and provide valuable forage for livestock and wildlife. Limited research has been conducted concerning kochia seed production. This research was conducted to evaluate the impact of harvest date on seed yield and germination of seven forage kochia accessions. Plants were grown in a field trial and seed was harvested in October, November, and December of each year and seed yield, 100-seed weight, and germination were measured. Parameters differed significantly across accession and harvest date and the interaction effect ($P < 0.05$). October had the lowest 100-seed weight and germination with all 100-seed weights and germination percentages ranking lowest for all accessions when compared to other months with the exception of the germination percentage of KZ6Xsel. Immigrant, BC-118, Pustsel, and Snowstorm ranked highest for seed yield all occurring in November with the exception of Pustsel, which occurred in October (20.3, 17.0, 15.1, 14.8 g plant^{-1}, respectively). Seed ripening of forage kochia is highly variable across accessions and even varies among plants within accessions. These results demonstrate seed trait differences among accession and confirm the importance of selecting an ideal harvest date to maximize viability and yield.

Introduction

The success or failure of restoration and revegetation efforts of forbs and shrubs on western rangelands depends on acquiring sufficient quantities of quality seed (Van Epps and Stevens, 2004). Seeds of forbs and shrubs do not ripen evenly and judgment must be used to determine the most ideal time to harvest (Stevens et al., 1996). Factors that influence the rate of maturation and ripening include temperature, soil nutrients and moisture, length of growing season, photoperiod, light quality, length of growing season, and also the position of the seed on the plant (Baskin and Baskin, 1973). Seed of some forbs and shrubs begin to ripen at the basal end of the seed head, spike, or raceme (Stevens et al., 1996). Seed producers must often compromise between seed maturity and loss of yield due to shattering when selecting a harvest date (Stevens et al., 1996).

Bassia prostrata (L.) A.J. Scott (synonym = *Kochia prostrata* (L.) Schrad), a semi-evergreen, sub-shrub of the Chenopodiaceae family, is more commonly referred to as forage kochia. Two subspecies commonly recognized are ssp. *virescens* (Frenzl) Prat., a green type forage kochia, and ssp. *grisea* Prat., a gray type forage kochia (Balyan, 1972). ‘Immigrant’ ssp. *virescens* was released in March of 1984 (Stevens et al., 1985) and recently (2012) the first cultivar of ssp. grisea was released as ‘Snowstorm’ (released March 22, 2012 by USDA ARS and Utah State University, USDA-ARS docket P.0017.12). Immigrant was selected for its ability to enhance rangelands by establishing on highly disturbed sites while reducing soil erosion and providing valuable forage (Stevens et al., 1985; Harrison et al., 2000). Forage kochia is a deep taprooted perennial with roots reaching depths over 4 m and lateral roots stretching up to 1.5 m (Kashkarov and Balyan, 1989). Flowers are found on the upper stems clustered on a spicate to paniculate inflorescence and bloom in the late summer and fall (Harrison et al., 2000). Seeds are often called utricles which are characterized by a pouch that has five small wings that contain the seed and have a diameter of approximately 2 mm. There are approximately 395,000 pure live seed per pound of forage kochia seed (Koch and Asay, 2001; Harrison et al., 2000).

Forage kochia is an important plant in its native environment of central Eurasia and has proven to be an increasingly important plant in the western United States. Waldron et al. (2011) characterized forage kochia as a high protein forage that increases the nutritional value, carrying capacity, and overall livestock performance on western rangelands. Forage kochia is highly salt tolerant (Francois, 1976; McFarland et al., 1990) and drought tolerant (Romo and Haferkamp, 1988), and has been used extensively to rehabilitate severely disturbed sites in harsh environments where other plant materials have struggled to establish and persist. These environments have included road-side and roadcuts (Blauer et al., 1993), processed oil shale, other types of mine spoils, and disturbed mine sites (Ferguson and Frischknecht, 1985; McKell, 1986). Successful establishment of forage kochia in these harsh environments has prevented soil erosion, flooding, and stabilized highly disturbed blow out areas (Stevens et al., 1984; Rasmussen et al., 1992). Forage kochia has been able to compete with and suppress invasive annual weeds that are common in the western U.S. (Van Epps and McKell, 1983; McArthur et al., 1990; Stevens and McArthur, 1990; Monsen, 1994; Koch and Asay, 2001; Young and Clements, 2004). In addition, forage kochia is a fire tolerant plant (McArthur et al., 1990) that remains green through the fire season. Thus, it is one of a few plant species often used in greenstrips to suppress wildfires (Harrison et al., 2002). These beneficial uses have promoted the use of forage kochia in the western U.S. and it has now been seeded on over 200,000 ha. (Gray, 2011).

Seed dormancy and slow germination rates are germination timing mechanisms of forage kochia that are known to prevent germination during periods that do not favor establishment (Meyer and Monsen, 1991). A large portion of freshly harvested forage kochia seed remains dormant until late winter or early spring (Balyan, 1972). Seed dormancy is often associated with species from unpredictable environments (Meyer and Monsen, 1992), which is a common trait among plants in arid rangelands where rainfall tends to be highly variable. Conversely, Meyer and Monsen (1991) found that for mountain big sagebrush (*Artemisia tridentate* ssp. *vaseyana* [Rydb.] Beetle), a shrub that is common in areas where forage kochia has been established, having a slow germination rate may have been almost as effective as dormancy in preventing premature germination of seeds. Forage kochia combines both mechanisms with seed dormancy and asynchronous germination, which should allow for some seeds to germinate when conditions favor seedling survival (Monsen and Kitchen, 1994). Furthermore, Waller et al. (1983) suggested that these germination controls likely form near the end of forage kochia seed ripening.

The period of seed ripening of forage kochia is highly variable (Balyan, 1972). Depending on the subspecies, seed ripening begins as early as late September and is completed as late as early December (Moghaddam, 1978; Kashkarov and Balyan, 1989; Davenport, 2005). Seed also ripens unevenly across individual plants of the same subspecies, and will even vary on the same raceme (Balyan, 1972). This delay in maturity of individual seeds on individual plants may vary up to 30 days (Balyan, 1972).

Ripening of forage kochia is affected by the weather, and freezing temperatures can hasten seed maturation (Harrison et al., 2000; USDA NRCS, 2012). Baskin and Baskin (1973) reported that ripening can vary from year to year due to the length of the growing season, soil nutrients, and available soil moisture. The variability of ripening between plants and subspecies, combined with the effect of ripening on germination controls, makes knowing the appropriate harvest date to maximize seed viability and yield extremely important. The objective of this study was to measure the differences in total seed yield, 100-seed weight, and germination among different accessions of forage kochia in response to different seed harvest dates. The results from this study will aid in selecting the appropriate harvest date for different accessions and will elucidate the effects harvest timing has on seed quality and yield.

Materials and Methods

The experiment was established in 2006 at the Utah Agriculture Experiment Station Blue Creek Research Farm (Latitude and Longitude; 41.9335, -112.438), located approximately 15 miles northwest of Tremonton, Utah and at an elevation of 1,582 m. During the three years of this study, the annual precipitation was 30 cm with 40% of the total precipitation coming during the months of April through August when forage kochia is actively growing. Seven accessions of forage kochia, representing both early and late maturing types of subspecies *virescens* and *grisea* were used in this study. Included among these accessions are the commercially available cultivars Immigrant and Snowstorm. Immigrant, subspecies *virescens*, was released in 1984, and is considered the forage kochia standard. Snowstorm, subspecies *grisea*, was released in 2012 and developed from collections from Uzbekistan (Waldron et al., 2005) and is 64% taller and produces 68% more forage than Immigrant (released March 22, 2012 by USDA ARS and Utah State University, USDA-ARS docket P.0017.12). The remaining five accessions are experimental and breeding lines originating from collections made from the native habitat of forage kochia. U-20 was collected in Stavropol', Russia, and is a *grisea* subspecies forage kochia (McAcarthur et al., 1996). Pustsel, a diploid, subspecies *virescens*, and Sahsel, a tetraploid, subspecies *grisea*, also trace to Uzbekistan collections (Waldron et al., 2005). KZ6Xsel, a hexaploid, subspecies *grisea*, is a selected population originating from Kazakhstan collections (Waldron et al., 2001). The last experimental line used was BC-118, a diploid *virescens* forage kochia collected from Uzbekistan. Forage kochia seedlings were transplanted from cone-tainers (Ray Leach Cone-tainer Cells, Stuewe and Sons Inc., 2290 SE Kiger Island Drive, Corvallis, OR) into 10-plant plots in a randomized complete block design with four replications. The nursery was surrounded by a border row of Immigrant to eliminate edge effects. The spacing was 1 m between rows and 0.5 m between plants within rows.

Harvests were conducted the first week of October, November, and December of 2008, 2009, and 2010. At each harvest, three individual plants from each plot were harvested by cutting and bagging all seed bearing stems. The bags were placed inside a greenhouse to air dry until the seed could be easily stripped from the stems. The stripped seed and remaining small stems, leaves, and chaff were run through a thresher (Winterstieger LD 180 st4, Wintersteiger Inc., 4705 Amelia Earhart Drive, Salt Lake City, UT) to separate seed still remaining on the small stems and to remove utricles from seed. The seed was sifted to remove any debris larger than the seed and then was cleaned using a seed blower (Carter Day International, Style# CFZ1, Carter Day International, Inc., 500 73rd Avenue N.E., Minneapolis, MN) to remove light material. If additional cleaning was needed to remove inert material, then seed was blown manually using a column seed cleaner (Agriculex CB-1 Column Seed Cleaner, Agriculex Inc., 1-59 Suburban Ave., Guelph, Ont., Canada). Following seed cleaning, seed for each collection was weighed to determine total yield for each plant harvested. Seed from each plant were manually separated from remaining foreign material, counted by hand into three replicates of 50-seed sub-samples, and weighed.

After seed preparation, germination boxes (Acrylic Germination Boxes, 11 cm, Cont 156C, Hoffman Manufacturing Co., Albany, OR) with two layers of blotter paper (Number 3, Steel Blue Germination Seed Blotters, 10 cm × 10 cm, Saint Paul, MN) positioned in the bottom of the boxes, were saturated with deionized water, and 50-seed sub-samples were arranged on top of the blotter paper. Care was taken to space the seeds so that they were not in contact with one another. Each box was treated with two sprays of 1% chlorine solution from a spray bottle that served as a fungicide. The boxes were covered and arranged in a randomized complete block design in an incubator to pre-chill at 2.5 °C for 14 days. Pre-chilling allows the seeds to imbibe moisture and overcome any dormancy or asynchronous germination that may be present. After this pre-chill period, the temperature was increased to 20 °C for 7 days. This germination procedure for forage kochia adheres to the standards set by the Association of Official Seed Analysts (AOSA, 2002). Following incubation, careful counts were made to determine the number of germinated seeds in each germination box. Seeds were considered germinated when the radical had extended approximately 5 mm. Total viable seed produced per plant was calculated by multiplying total seed produced by the germination percentage.

All data were analyzed using the Proc Mixed procedure of SAS (Littell et al., 2006) with replication and years as random variables, and month and entry as fixed effects. Mean comparisons were made among treatments using Fisher Protected LSD tests at the $P = 0.05$ level of probability (Steel et al., 1997). Entry by month of harvest interactions were statistically and biologically significant for all traits, therefore all means comparisons were done on the entry × month basis. Two sets of data were not available for the analyses. The germination of October 2009 seed was hampered by fungi which limited germination significantly, and an early snow storm covered the research nursery in 2010 making a December harvest impossible. Simple correlations among seed traits were calculated using the CORR procedure of SAS.

Results and Discussion

The month of harvest, forage kochia accession, and the month by accession interaction were all significant for seed yield (Table 3-1). The high significance ($P<0.0001$) of the month by accession interaction for seed yield, 100 seed weight, and germination makes the interaction effects more meaningful.

100-Seed Weight and Germination

Month, accession, and month by accession interaction had highly significant ($P<0.0001$) effects on 100-seed weight values (Table 3-1). Immigrant, long considered the standard of forage kochia, ranked among the lowest in 100-seed weight (45.5, 93.9, and 87.0 mg in Oct., Nov., and Dec., respectively) (Table 3-2). October harvested seed ranked last in 100-seed weight for all accessions (Table 3-2) and November harvested seed trended slightly higher than December. The newly released cultivar Snowstorm and Sahsel, both of the subspecies *grisea*, had significantly higher 100-seed weights than the other accessions having peak 100-seed weights in November of 154.7 and 143.3 mg respectively (Table 3-2). Both are tall-type forage kochias, and Immigrant, which ranked last, is a short type forage kochia. BC-118 was the highest ranking 100-seed weight of three ssp. virescens in the study with a mean of 122.9 mg in November compared to Pustsel (107 mg) and Immigrant (93.9 mg) (Table 3-2). The lowest ranking ssp. *grisea* accession in November was KZ6Xsel (79.7) which incidentally ranked lowest among all accession for November (Table 3-2). October seed weights were light, due to immature seed; hence all seven 100-seed weights were grouped last in table 3-2. Due to the limited research that is available concerning harvest and 100-seed weight of forage kochia, this research is particularly beneficial in understanding how 100-seed weight is influenced by harvest date.

Germination was measured in this trial as a means to determine the viability of the seed harvested. In this study, the month of harvest, accession, and the month by accession interaction were all highly significant for germination of forage kochia (Table 3-1). Similar to the 100-seed weights, germination in the month of October ranked last when compared to other months for all accessions except KZ6Xsel (60.4%) which ranked significantly higher (Table 3-3). Incidentally, KZ6Xsel had the lowest ranking among ssp. *grisea* in 100-seed weight (mean of 77.4 mg Table 3-2). There was little statistical difference between November and December germination for most entries. These contrasts in overall 100-seed weight and germination contributed to a statistically nonsignificant correlation between 100-seed weight and germination (*P*=0.1094). However, month × entry trend suggest that increases in germination within an entry correspond to increases in 100-seed weight (Figure 3-1). This suggests that large differences in 100-seed weight between genotypes (entries) masked the true relationship between seed weight and germination in forage kochia.

Bai et al. (1997) found that heavy Wyoming big sagebrush seeds germinate more quickly and at higher rates than lighter seeds and Waldron et al. (2006) observed similar rankings of seed yield and 100-seed weight among western wheatgrass populations. In this study, there was no overall correlation between 100-seed weight and germination (r=0.12, *P*=0.1094) and very low correlation between seed yield and germination (r=0.21, P=0.0068) and seed yield and 100-seed weight (r=0.21, *P*=0.0028).

Factors influencing the germination of forage kochia have been of interest to researchers as a result of the difficulty of establishing forage kochia and maintaining seed viability (Waller et al., 1983; Haferkamp et al., 1990; Stewart et al., 1999; Kitchen and Monsen, 2001). However, the relationship between harvest date and germination is not well understood. Stewart et al. (1999) observed that germination characteristics are driven by the genetics of each plant and also influenced by maternal environment. This study was conducted at a single location where the maternal environment was consistent for all accessions. Stewart et al. (1999) also reported maturity as important for viability at the time of harvest and of little importance for establishing germination controls of forage kochia seed. The level of maturity at the time of harvest in this study also appeared to be an important factor for ensuring seed viability.

Total and Viable Seed Yield

Mean seed yield per plant was significantly different for each month of harvest. Seed harvested in October was generally not fully developed for all accessions except KZ6Xsel and Pustsel which had peak seed production occur in October (Table 3-4) and also had satisfactory germination during the same month (Table 3-3). Immigrant, BC-118 and Pustsel, of ssp. virescens, had the highest seed yield of all accessions (20.3, 17, 14.8g, respectively) with the exception of the cultivar Snowstorm (ssp. *grisea* 15.1g) (Table 3-4). Immigrant was originally selected for release as a cultivar partly due to its high seed production (Stevens et al., 1985) and continues to perform above other accessions. Pustsel was one of the highest seed producers in October (15.1 g) as it matures earlier than most accessions (Table 3-4). However, it demonstrated its vulnerability to shatter mature seed as seed yield declined in November, (7.5g) and continued declining to 0.7g in December (Table 3-4). The remaining accessions all yielded the most seed in November, resulting in November being the highest ranked month for seed yield. December had the lowest seed yield due to loss of mature seeds shattering prior to harvest (Table 3-4). Wind, rain, and snow can dislodge mature seed from the stems of forage kochia prior to harvest causing yield loss. During the course of the study, the first hard frosts for each year occurred October 1, 2009, and on October 25 for both 2010 and 2011. The USDA NRCS (2012) Plant Guide suggested a hard frost is required before seeds will mature. However, the variability of seed yield and viability demonstrated in this study suggests maternal genetics play a larger role in determining when maturation occurs.

Seed yield and viability parameters in any seed crop are associated with the stage of maturity at which the seed is harvested (Vasudevan et al., 2008). The quantity (g plant^{-1}) of viable seed (total seed × % germ) for each harvest and accession was calculated to better understand the correlation between yield and maturity of forage kochia seed harvested on different dates. This value is beneficial to determine the ideal harvest date that maximizes viable seed yield. Immigrant ranked significantly highest among accessions in November (11.8g) and was among the highest ranked in December (7.2g), though not significantly different than nine other entry/month combinations including December harvests of U-20 (3.7g) and Sahsel (3.6g) (Table 3-5). Figure 3-2 illustrates the trend over time for total seed yield and corresponding viable seed yield by accession. KZ6Xsel and Pustsel are the only two accessions with greater viable seed yield in October (8.7 and 4.7g, respectively) than the following months of November (2.1 and 3.9g, respectively) and December (1.6 and 1.2g, respectively) (Figure 3-2). The remaining accessions have similar trends, peaking in November, and declining in December. Similar to total seed yield, viable seed yield of all accessions declined in December suggesting seed had matured and had begun to shatter and fall on the ground resulting in loss of yield (Figure3-2). The seed that remained on plants in December and was harvested, yielded significantly less total and viable seed yield than previous months though the amount of separation between the means was not significantly different for all accessions except Immigrant (Figure 3-2).

Baylan (1972) reported uneven ripening among plants within forage kochia accessions. The forage kochia accessions used in our study also demonstrated high variability not only among accessions, but within accessions among individual plants

(Figure 3-3). Although Davenport (2005) proposed that in some cases ripening might not be complete until early December, these results suggest sufficient ripening had taken place to warrant harvesting before seed shatter causes a loss of yield (Figure3-4). Hence, the ideal harvest time of any crop is immediately before the loss of mature seeds exceeds the amount of seeds yet to reach maturity (Steckel and Steckel, 1983, 1986). Although morphological changes of forage kochia plants were not noted in this study, Waller et al. (1983) suggested forage kochia seed should be harvested when seeds can be easily hand stripped from the inflorescence. The variation in germination across and within accessions (Figure 3-3) suggests the possibility to select and develop breeding lines that mature earlier or later. Results similar to Figure 3-3 were present for all other traits in the study. Selecting and breeding forage kochia to reduce seed maturity variability could ease the difficulty of selecting a harvest date and would allow for higher yield and viability than is currently possible with the amount of variability currently found within accessions.

This research compared the seed yield, germination, 100-seed weight, and viable seed yield between different harvest dates of seven accessions of forage kochia. In this study we found that harvesting forage kochia before maturity will result in poor yield and viability due to the high number of immature and undeveloped seeds. Delaying a harvest until after maturity will affect seed yield due to shattering of mature seed. Given the high variability of yield, 100-seed weight, and germination currently observed within forage kochia accessions, selection and breeding programs to reduce variability would simplify the task of choosing an appropriate harvest date and increase viable seed yield. In conclusion, harvest date affects the total and viable seed yield, 100-seed weight, and germination of forage kochia. Harvest dates should be selected to maximize viable seed yield. Careful considerations should be made when selecting a harvest date as harvesting too late can be just as detrimental as harvesting too early. Optimum month of seed harvest for experimental lines of forage kochia was variable, and there were no obvious trends unique for the two subspecies grisea and virescens. In the environment under which this research was conducted, both currently available cultivars, Immigrant and Snowstorm, should be harvested in mid-November to maximize viable seed.

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Table 3-1. Significance of main and interaction effects on seed traits of seven forage kochia accessions as affected by harvest date. Seed was produced over three years (2009, 2010, and 2011) near Blue Creek, Utah and harvested in October, November, and December of each year.

	Germination %	100-Seed wt.	Seed yield	Viable seed
	P-value			
Month	<0.0001	<0.0001	<0.0001	<0.0001
Entry	<0.0001	<0.0001	0.0045	0.0025
Month × Entry	<0.0001	<0.0001	<0.0001	<0.0001

Table 3-2. 100-seed weight means of seven forage kochia accessions as affected by harvest dates in October, November, and December during three years (2009, 2010, and 2011), grown near Blue Creek, Utah.

Month	Entry	Std. error	100-seed wt.†
			mg plant^{-1}
November	Snowstorm	7.7	154.7 a
November	Sahsel	7.7	143.3 a
December	Snowstorm	8.6	124.5 b
November	BC-118	7.6	122.9 b
December	Sahsel	8.6	119.0 bc
November	Pustsel	7.6	107.0 cd
December	BC-118	8.3	101.2 de
November	U-20	7.8	94.2 ef
November	Immigrant	7.6	93.9 ef
December	Pustsel	8.0	89.4 efg
December	Immigrant	8.0	87.0 efg
December	U-20	8.6	86.5 efg
December	KZ6Xsel	8.0	81.6 fgh
November	KZ6Xsel	7.6	79.7 gh
October	Snowstorm	7.6	78.4 gh
October	BC-118	7.6	76.2ghi
October	Sahsel	7.6	71.5 hij
October	KZ6Xsel	7.6	70.9 hij
October	Pustsel	7.6	65.5 ij
October	U-20	7.8	60.2 j
October	Immigrant	7.6	45.5 k

†100-seed yield means followed by similar letter groups are not significantly different at *P*<0.05.

Table 3-3. Seed germination percentages of seven forage kochia accessions as affected by harvest dates in October, November, and December during three years (2009, 2010, and 2011), grown near Blue Creek, Utah.

Month	Entry	Std. error	100-seed wt.†
			% plant^{-1}
December	BC-118	15.7	64.2 a
October	KZ6Xsel	15.7	60.4 ab
December	KZ6Xsel	15.6	60.3 ab
December	U-20	15.9	59.9 abc
December	Pustsel	15.6	55.0 abcd
November	Immigrant	15.3	54.4 abcd
November	Snowstorm	15.4	53.8 abcd
December	Immigrant	15.6	53.7 abcd
November	Sahsel	15.4	52.7 abcd
November	KZ6Xsel	15.3	51.2 abcd
November	U-20	15.5	50.2 abcd
November	BC-118	15.3	48.4 abcd
December	Snowstorm	15.9	48.1 abcde
December	Sahsel	15.9	46.0 bcde
November	Pustsel	15.3	43.5 cde
October	U-20	15.9	43.4 cde
October	Pustsel	15.7	31.8 ef
October	BC-118	15.7	31.2 ef
October	Immigrant	15.7	23.3 fg
October	Sahsel	15.7	12.6 g
October	Snowstorm	15.7	11.2 g

†Germination percentages followed by similar letter groups are not significantly different at $P<0.05$.

Table 3-4. Seed yield means of seven forage kochia accessions as affected by harvest dates in October, November, and December during three years (2009, 2010, and 2011), grown near Blue Creek, Utah.

Month	Entry	Std. error	100-seed wt.†
			g plant^{-1}
November	Immigrant	2.6	20.3 a
November	BC-118	2.6	17.0 ab
October	Pustsel	2.6	15.1 abc
November	Snowstorm	2.7	14.8 abc
October	BC-118	2.6	13.7 bc
October	KZ6Xsel	2.6	13.4 bcd
November	U-20	2.8	12.7 bcde
November	Sahsel	2.7	11.9 bcdef
December	Immigrant	2.9	10.5 cdefg
October	U-20	2.8	7.8 defgh
November	Pustsel	2.6	7.5 efgh
October	Snowstorm	2.6	6.6 fghi
October	Immigrant	2.6	6.5 fghi
October	Sahsel	2.6	5.8 fghi
December	U-20	3.2	5.3 fghi
December	Sahsel	3.2	4.1 ghi
December	BC-118	3.1	3.7 ghi
November	KZ6Xsel	2.6	3.5 hi
December	Snowstorm	3.2	2.5 hi
December	KZ6Xsel	2.9	2.0 hi
December	Pustsel	2.9	0.7 i

†Seed yield means followed by similar letter groups are not significantly different at $P<0.05$.

Table 3-5. Viable seed yield of seven forage kochia accessions as affected by harvest dates in October, November, and December during three years (2009, 2010, and 2011), grown near Blue Creek, Utah.

Month	Entry	Std. error	100-seed wt.†
			g plant^{-1}
November	Immigrant	1.98	11.81 a
October	KZ6Xsel	1.98	8.74 b
November	BC-118	1.98	7.98 bc
November	Snowstorm	2.01	7.87 bc
November	U-20	2.05	7.39 bcd
December	Immigrant	2.09	7.17 bcde
November	Sahsel	2.01	7.07 bcde
October	BC-118	1.98	5.48 cdef
October	Pustsel	1.98	4.69 defg
November	Pustsel	1.98	3.86 efgh
December	U-20	2.22	3.66 efgh
December	Sahsel	2.22	3.61 efgh
October	U-20	2.05	3.51 fgh
December	BC-118	2.15	3.04 fgh
December	Snowstorm	2.22	2.17 fgh
November	KZ6Xsel	1.98	2.10 gh
October	Immigrant	1.98	1.68 gh
December	KZ6Xsel	2.09	1.65 gh
October	Sahsel	1.98	1.30 h
October	Snowstorm	1.98	1.25 h
December	Pustsel	2.09	1.22 h

†Viable seed yield means followed by similar letter groups are not significantly different at $P<0.05$.

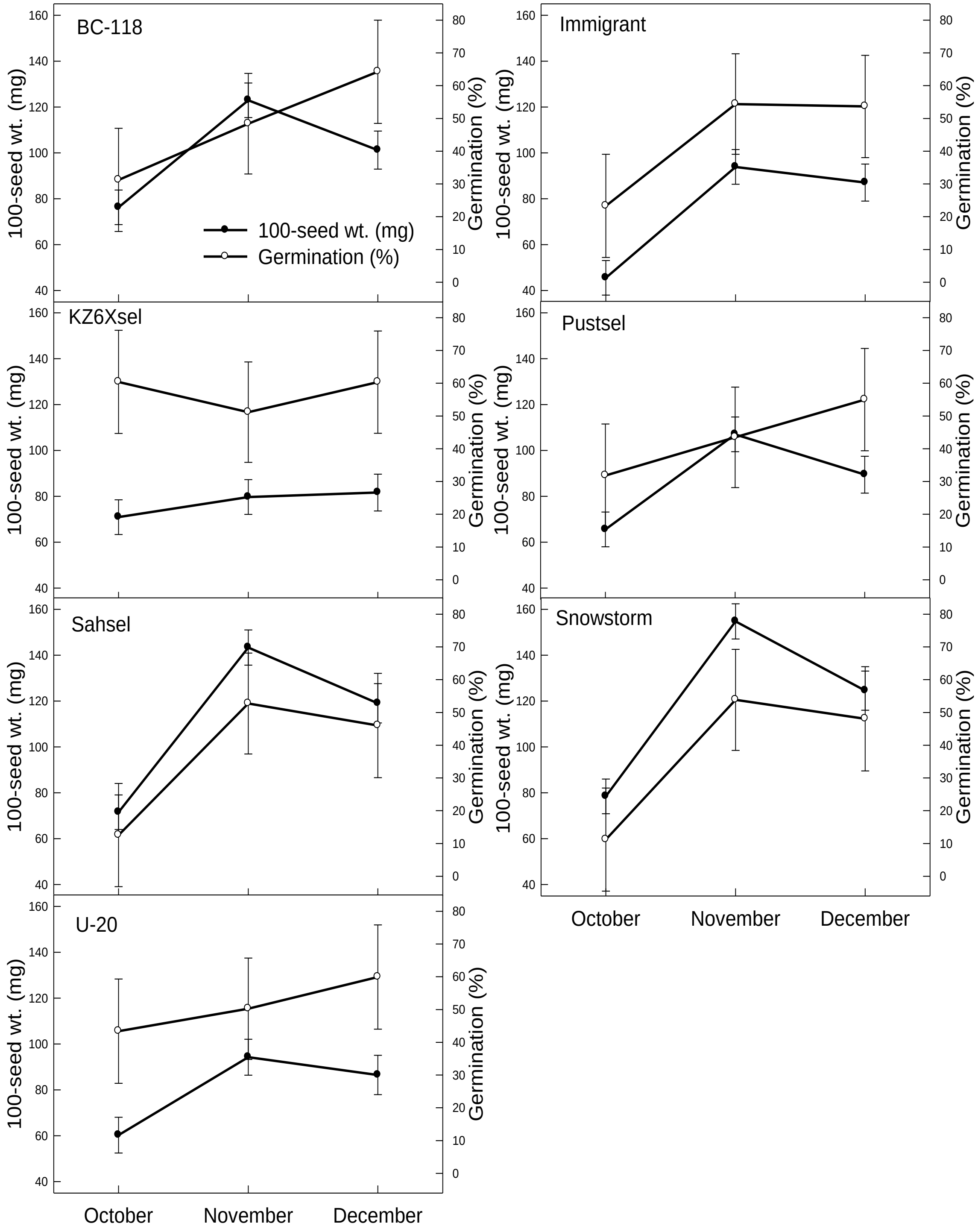

Figure 3-1. Mean response of 100-seed weight (mg) and germination (%) of seven accessions of forage kochia harvested in October, November, and December of 2009, 2010, and 2011. Whiskers represent the standard errors of the means (n=6).

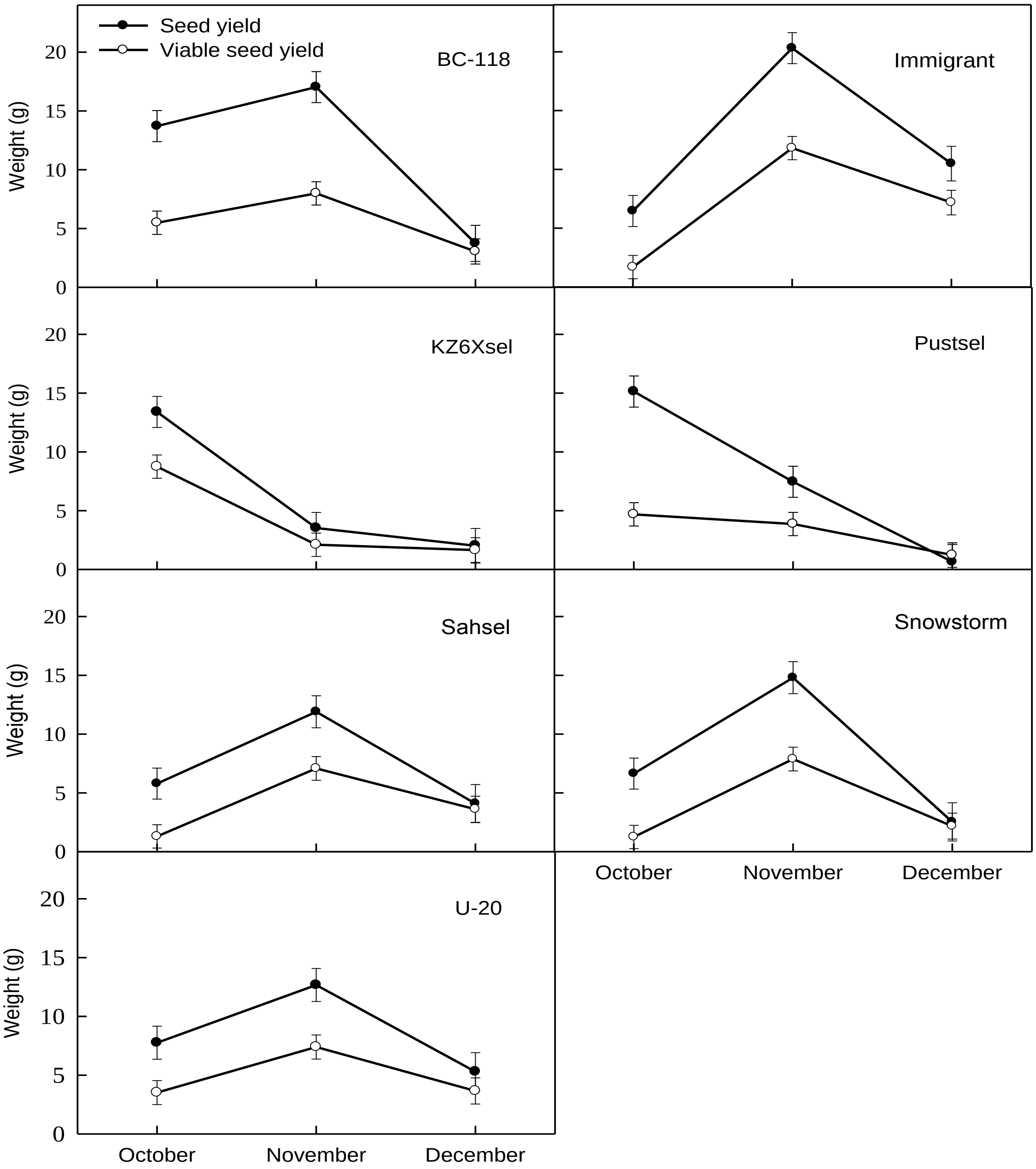

Figure 3-2. Mean response of total seed yield and viable seed yield (g plant^{-1}) per plant of seven accessions of forage kochia harvested in October, November, and December of 2009, 2010, and 2011. Whiskers represent the standard errors of the means.

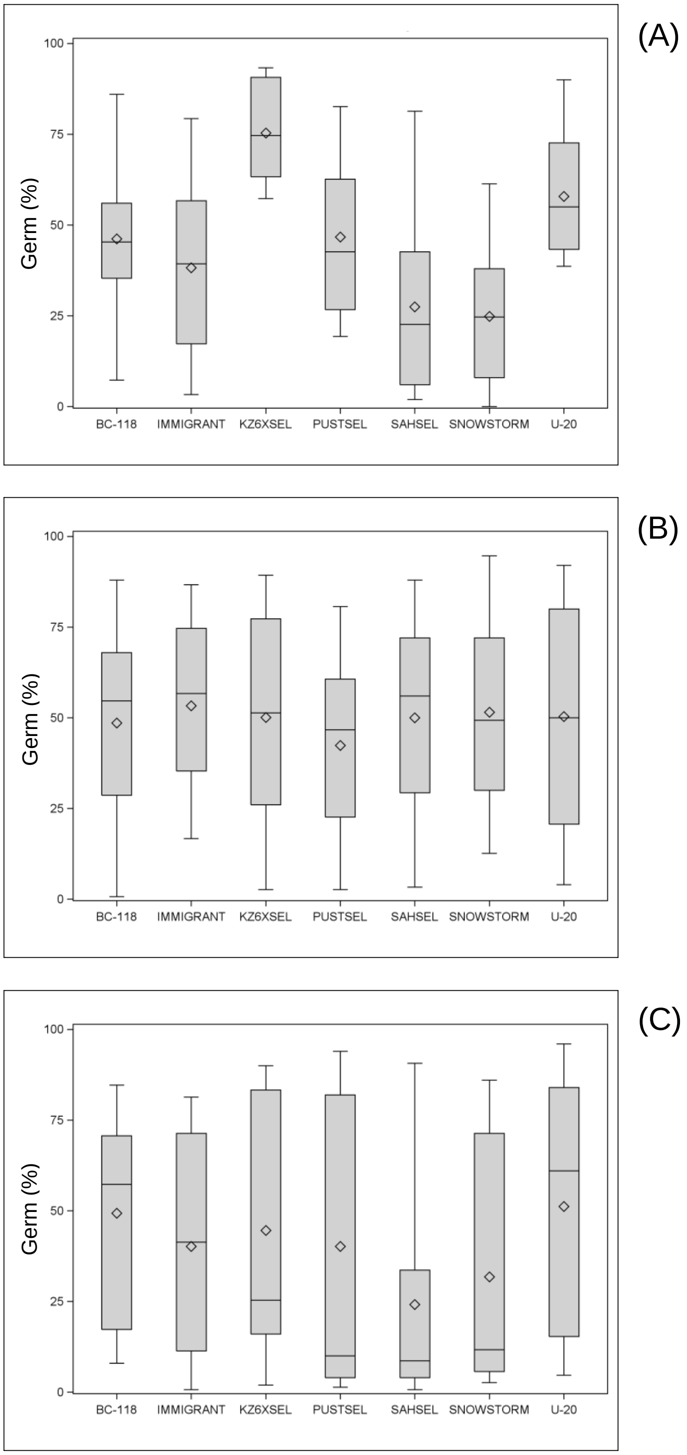

Figure 3-3. Skeletal boxplot graphs of the variability in germination (%) of seven forage kochia accessions from three harvests dates in October (A), November (B), and December (C) in 2009, 2010, and 2011. Whiskers represent the range of values. The top and bottom of each box is the 75th and 25th percentile, respectively, and diamonds and lines represent the mean and median, respectively.

CHAPTER 4

SUMMARY AND CONCLUSIONS

This research has greatly expanded the current knowledge and understanding of the ever more utilized forage kochia. This work furthers the understanding of the critical period from when the seed is seeded until it germinates in the field and the influence that harvest date can have on seed production of multiple forage kochia accessions.

The germination study described in this paper provides insight into the germination response of two accessions of forage kochia to external influences. Regardless of planting date, location, or age of seed, Sahsel, representative of subspecies *grisea*, exhibited higher germination percentages than Immigrant, subspecies *virescens*. The germination percentage 30 days after planting of Sahsel was also higher suggesting a more rapid germination rate compared to Immigrant. The higher germination percentages of Sahsel suggest it may benefit from added energy due to a larger seed size that is almost twice the size of Immigrant seed. Germination of year-old cold-stored seed of Immigrant in the field was 90% less than the current-year fresh seed, while the trend was similar for Sahsel, with an 84% reduction between fresh and old seed. This large difference in germination percentage of the current-year seed and the year-old cold stored seed is likely related to seed vigor. Planting in January and February resulted in the highest germination rates. February had a higher germination rate at 15 days after planting which is likely the result of more favorable temperatures when compared to the 15 days after planting of January. The risk of forage kochia seed failing to germinate increases substantially when soil moisture is transient and only moist for short periods after rains. Planting forage kochia early in the season when snow is present or likely to occur allows forage kochia seed to imbibe moisture at cold temperatures which enhances germination when temperatures are favorable. Planting fresh, recently harvested seed should be a priority when possible to ensure success. If planting year-old cold-stored seed, germination and vigor tests should be used to determine an appropriate seeding rate.

This research also identified the effect of harvest timing on seed properties and germination. The month of harvest, forage kochia entry, and the month by entry interaction all significantly influenced seed yield, 100-seed weight, and germination. KZ6Xsel and Pustsel had peak seed production occur in October while the remaining accessions had maximum production occur in November. December had the lowest seed yield due to mature seeds shattering prior to harvest. Immigrant and BC-118 were the highest seed producing accessions when averaging all harvests (12.4 and 115 g, respectively. Immigrant, ranked last in 100-seed weight (75.5 mg) while the newly released cultivar Snowstorm and Sahsel had the highest 100-weight (119.2 and 111.3 mg, respectively). Considering the yield of viable seed from each harvest, Immigrant ranked highest among accessions in November (11.8g) and was among the highest ranked in December (7.2g), not significantly different than U-20 (3.7g) and Sahsel (3.6g). KZ6Xsel and Pustsel are the only two accessions with greater viable seed yield in October (8.7 and 4.7g, respectively) than the following months of November (2.1 and 3.9g, respectively) and December (1.6 and 1.2g, respectively). This suggests that KZ6Xsel and Pustsel are early maturing accessions. The remaining accessions, although different, trend similarly from October, peaking in November, then decline to December. Harvesting forage kochia early before adequate levels of maturity have been reached results in poor yield and viability due to the high number of immature and undeveloped seeds.

In summary, results from this research demonstrated variability across accessions and within accessions of forage kochia. These large ranges of variability suggest that future selections and breeding for desired traits in forage kochia may be possible to improve accession quality. Planting early in the year when snow and moisture events are prevalent and temperatures are low provide forage kochia the best opportunity to imbibe moisture and germinate. Harvesting before seed fully matures can be detrimental to seed viability. Seed should be harvested soon after the majority of seed matures to reduce yield loss due to shattering.