Improvement of chickpea stand establishment in cool soils
by Shirley Ann Bollinger

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Agronomy
Montana State University

Abstract:
Chickpea germinates poorly in cool soil and seedling establishment is highly variable. The objective of studies undertaken was to find out why chickpea performs poorly in pool soil and to evaluate storage conditions, seed moisture content, seed priming, location grown and seed vigor as ways to improve chickpea stand establishment.

Field and laboratory trials indicated cool storage increases germination and lessens hard seed expression when planted in cool soil. Further experiments controlling storage temperature and relative humidity indicated elevated seed moisture content also reduced hard seed. Seed priming with polyethylene glycol increased percentage germination, reduced hard seed and increased the speed of germination. Chickpea grown at three locations, Pullman and Lind, Washington and Manhattan, Montana, had significantly different amounts of hard seed, with the Manhattan location having the least. A greenhouse study and several seed vigor tests, including; cool germination, seedling growth rate, electrical conductivity, and accelerating aging were conducted on eight chickpea seedlots to determine which tests would give the most accurate estimate of chickpea seed vigor. Accelerating aging proved to be the most reliable test in predicting seed vigor.

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Shirley Ann Bollinger

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3-17-1987
Date

Loren E. Wiesner
Chairperson, Graduate Committee

Approved for the Major Department

March 17, 1987
Date

Dwane H. Miller
Head, Major Department

Approved for the College of Graduate Studies

April 8, 1987
Date

Henry L. Parsons
Graduate Dean

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ABSTRACT

Chickpea germinates poorly in cool soil and seedling establishment is highly variable. The objective of studies undertaken was to find out why chickpea performs poorly in cool soil and to evaluate storage conditions, seed moisture content, seed priming, location grown and seed vigor as ways to improve chickpea stand establishment.

Field and laboratory trials indicated cool storage increases germination and lessens hard seed expression when planted in cool soil. Further experiments controlling storage temperature and relative humidity indicated elevated seed moisture content also reduced hard seed. Seed priming with polyethylene glycol increased percentage germination, reduced hard seed and increased the speed of germination. Chickpea grown at three locations, Pullman and Lind, Washington and Manhattan, Montana, had significantly different amounts of hard seed, with the Manhattan location having the least. A greenhouse study and several seed vigor tests, including; cool germination, seedling growth rate, electrical conductivity, and accelerating aging were conducted on eight chickpea seedlots to determine which tests would give the most accurate estimate of chickpea seed vigor. Accelerating aging proved to be the most reliable test in predicting seed vigor.

CHAPTER I

INTRODUCTION

Chickpea (*Cicer arietinum* L.) is a cool-season crop with alternative crop potential for Montana. Variable market conditions, increased disease problems in specific United States production areas, increased market value, and crop rotation potential with small grains has increased interest in chickpea production in the northwestern United States. Montana has the cool, dry climate required for growing chickpea. However, because of the short growing season, seeds must be planted in cold soils, causing establishment problems. Preliminary studies indicate that cold germination temperatures increase hard seed. High vigor seed reduces the probability of stand failure. Higher vigor seed enhances stand establishment under unfavorable conditions.

High vigor chickpea seeds, with proper treatment, will germinate better in cool soils. Also, better yields are obtained with early planting.

The main objectives of this study were to find a treatment to reduce hard seed under cool conditions and to determine which seed vigor tests would be most accurate in determining high vigor seed.

CHAPTER II

LITERATURE REVIEW

Crop

Chickpea (*Cicer arietinum* L.), also called garbanzo bean, is a cool-season legume which originated in Asia Minor. The earliest record of its use is 5450 B.C. in Turkey. Its cultivation spread eastward to India and westward to the Mediterranean (Simmonds, 1976).

Chickpea, and other grain legumes, provide the major protein source for people in Asia, Africa and Latin America. Chickpea is a good dietary complement to cereals because of the high lysine content and 20-22% crude protein which is 80% digestable. Proper chickpea and cereal mixtures can provide all the essential amino acids for humans. The carbohydrate (50-60%) and oil (5%) content of chickpea, contribute to energy requirements (Simmonds, 1976). Chickpea utilizes atmospheric nitrogen and has maintained soil fertility in some areas of India for centuries (Van Der Maesen, 1972). As compared to other grain legumes, chickpea is second in area planted (exceeding ten million hectares) and third in quantity produced (6.3 million metric tonnes) in the world.

There are two types of chickpea. The large-seeded kabuli type is grown primarily as a summer crop in the

Mediterranean. The small-seeded desi type is grown during the winter in Asia. Eighty-five percent of the world's production of chickpea is the desi type which is grown in India, where they are processed into dhal (split pea without seed coat) for human consumption. Seeds are eaten fresh, parched, boiled, fried and sprouted for salads. They are also dried and ground into flour for snacks and sweetmeats. Young plants and green pods are eaten like spinach. A favorite hors d'oeuvres in the Mediterranean area is hummus, which is mashed kabuli chickpea mixed with oils and spices (Duke, 1981). Other uses include production of starch for textile sizing, adhesive for plywood and an indigo like dye from the leaves. Seed, husks, leaves and stems are used to feed horses and cattle. Granular secretions of malic and oxalic acids from leaves, stems and pods are used both medicinally and as a vinegar. A cooked chickpea and milk mixture can be fed to infants to control diarrhea (Duke, 1981).

Chickpea is also grown in South America, Mexico and the United States. The United States produces approximately 3500 metric tonnes. California produces approximately 3240 hectares and the Palouse region of eastern Washington and western Idaho produce approximately 2000 hectares of chickpeas (Welty, et al, 1982). Disease problems in other areas, market value ($25-50/cwt), nitrogen fixing ability, and rotation benefits with small grains make chickpea a

promising crop for some areas of Montana. Montana's cool, dry summers should provide the right environment for production of chickpea (Welty, et al, 1982).

Botanical Description

Chickpea (*Cicer arietinum* L.) belongs to the Papilionacaea subfamily of Fabaceae. Chickpea is a self-pollinated, branched, annual that reachs a height of 60 cm with a tap root ranging from 0.6 to 1.8 meters long. The leaves are odd-pinnately compound with three to eight leaflet pairs. The flowers (0.6 to 1.25 cm) are borne on inflorences that grow from the stem axes. The kabuli type has large leaflets and white flowers, while the desi type has small leaflets and flowers that are either white, pink, purplish or blue. The seeds are borne in pubescent pods (2 to 5 cm long) and have an anterior "beak and groove" about two-thirds of the distance around the seed (Muehlbauer, et al, 1982).

The chickpea seed coat is identified by two microscopic characteristics, the external palisade and "hour glass" cells (Corner, 1951). The seed coat has a blistered, undulating surface. Seed coats of desi type chickpea are three times as thick as the kabuli type. Desi seeds have several layers of palisade cells, while the kabuli has only one. (Singh, et al., 1984). The hilum is located in a sunken pouch below the seed surface with a second layer of palisade cells on top of the first layer. A vascular bundle

(tracheid bar) is located at the bottom of the pouch extending into the mesophyll. (Patel, et al, 1976). Under the seed coat surface is a layer of palisade cells, also called macrosclereids, which are typically very long with wavy, thickened cell walls (Chowdhury, 1970). There is a bulbous lumen with a curved outer end at the base of the cells. A 'mucilage stratum', found only in chickpea, is located below the palisade cells (Chowdhury, 1970). Osteosclereids, also called "hour glass" cells, are located between the mesophyll and the palisade cells. The osteosclereid ends are broad and come in contact with the adjoining osteosclereids only at the broad ends which providesa very large intersclereid space. The lateral walls adjacent to the intersclereid space are uniformally thick (Patel, 1976).

Growing Conditions

Optimum growing conditions for chickpea are: full sun on a south or east facing slope; a cool dry climate and a well drained soil with a pH of 5.5 to 8.6. They tolerate poor soils, but do best on heavy clay. Daily temperature fluctuations of 10-30 C with cold nights (18-21 C) and heavy dews are best for growth. Some cultivars can withstand -3 C in the early growth stage or under snow cover. Optimum annual rainfall is approximately 63-76 cm. *Rhizobium* inoculation on first-planted soil will increase chickpea yields 10-60% (Duke, 1981).

Welty, et al. (1982) have studied varietal responses, plant population for maximum yield, planting date, fertility, weed control and irrigation for production in Montana. They recommend a seeding rate of one to two seeds per linear foot in 15 cm rows (170-225 kg/ha) with an optimum planting date of May 7. Nitrogen fertilizer did not increase yields when seeds were inoculated with *Rhizobium*. Herbicides such as profuluralin, ethalfluralin, trifluralin and dinoseb provided excellent control of broadleaf weeds and metolachlor controlled green foxtail. Some irrigation may be necessary for maximum yields in Montana.

Hard Seed

Montana has a good late season for growing chickpea. However, because of the short growing season, seeds must be planted in cold soils which may cause establishment problems. Germination at 5 C caused an increase in hardseededness and reduced germination rates when seed was stored in warm conditions (23 C). Further experiments indicated that cool storage reduced hard seed content (Frisbee, et al., 1987). These data suggest that there is a relationship between seed coat permeability and storage temperature and/or relative humidity.

Hard seeds have been defined as seeds unable to imbibe water (Rolston, 1978). These seeds are common in many species of Fabaceae (legumes). The presence of a palisade

layer of macrosclerid cells is typical in water impermeable seed. The hardness and impermeability of the seed coat is caused by the contraction of the walls of the palisade cells as the seed ripens (Corner, 1951).

Another phenomenon of impermeability in the palisade cells is the light line (Corner, 1951). The cell wall in this region appears to be compact. Phenolic compounds are also thought to contribute to water impermeability (Esau, 1977). Riggio-Bevilacqua, et al. (1985) indicated that the cuticle is the impermeable layer in legume seeds. The hilum, which acts as a valve to prevent the entry of moisture into the seed, while permitting loss of moisture, may also contribute to hardseededness. This phenomenon is reported to cause a high degree of desiccation (Esau, 1977). The impermeability of the seed coat of *Cercis siliquastrum* (Judas tree) is affected by a combination of water failing to pass through the hilum and an inner non-cellular lipidic layer at the edge of the hypodermis (Riggio-Bevilacqua, 1985).

Hardseededness could be the result of low seed moisture. Soybean (*Glysine max* L.) studies conducted by Harrington (1949) showed that 15 days storage at 10 % relative humidity, resulted in a seed moisture of 7 % with 76.5 % hard seed. Fifteen days storage at 66.5 % relative humidity, resulted in a seed moisture of 11.3 % and 5.2 % hard seed. Seed stored for 60 days at 75 % relative humidity, had a resultant seed moisture of 12.5 % and no hard seed.

In another study done with white beans (*Phaseolus vulgaris* L.) by Lebedeff (1947), seeds were dried to ten different moisture contents ranging from 14.11 % to 5.39 %. There were no hard seeds in the control which contained 15.14 % moisture, but seed with 14.11 % moisture had 1 % hard seed. The percentage of hard seeds increased with each reduction in seed moisture content, when moisture content was reduced to 5.59 % almost 90 % of the seeds were hard. Permeability of West Austrailian blue lupine (*Lupinus digitatus* L.) directly related to the amount of seed moisture, with storage temperature not affecting hardseededness (Gladstones, 1958).

Environmental conditions during the growing season have been shown to affect the proportion of hard seeds produced by some annual legumes. According to Bewley and Black (1985), photoperiods can affect seed coat thickness and color. Phenolic substances produced during air drying are oxidized to dark-colored compounds that may contribute to hardseededness. Drying of the seed in some leguminous species is controlled by the hilum, which in turn is regulated by environmental conditions. When the relative humidity is low, the cells around the hilar fissure shrink, thus opening the tissue and allowing more moisture to escape. A cultivar of alfalfa (*Medicago sativa* L.) grown in different areas of the United States (USA) exhibited wide variations in the amount of hard seed (Gunn, 1972). Northwestern

USA grown alfalfa usually has 40 to 50 % hard seed, while alfalfa grown in southwestern USA seldom has more than 20 to 30 % hard seed. The effects of temperature during and immediately following maturation is believed to play a major role in determining the amount of hard seed. When temperatures are low, hard seed content is highest. Argel and Humphreys (1983) reported that temperature during seed formation of carribean stylo (*Stylosanthes hamata* (L.) Taub. cv. Verano) is an important factor modifying the development of hardseededness. More soft seed may be produced in cool areas, when flowering and maturation occurred during cold periods and in seasons which are abnormally cool. It is possible that temperature acts as a modifying factor on the development of hardseededness exerted by atmospheric humidity (Argel and Humphreys, 1983). Hardseededness after 120 days storage at 77 and 32 % relative humidty was positively correlated to temperatures of 21, 24 and 27 C. Correlation coefficients between seed pod moisture content and percentage hard seed were greater as temperature decreased. Argels and Humphreys, 1983) gave no evidence that variations in soil moisture supply or levels of illuminance influenced hardseededness.

The length of the growing period in the spring months may be a critical factor in the development of hardseededness in subteranean clover (*Trifolium subterraneum* L.) Environments with relatively long spring growing periods

caused a higher proportion of hard seed and plants maturing under soil moisture stress produced fewer hard seed. High soil moisture availability during seedfill of soybeans reduces hard seed by disrupting seed-coat integrity (Hill, et al, 1986).

Argels and Humphreys, 1983, also identified some morphological characteristics of the seed which are changed by temperature which influence seed moisture content and the development of hardseededness. Carribean stylo seed formed under high temperature had more lignin and hemicellulose, less cellulose, and shorter palisade cells than seed formed under cooler temperature. The testa of hard seed had a more regular, even reticulate surface than that of soft seed.

Seed Priming

The partial imbibition of seeds in polyethylene glycol (PEG) is called osmoconditioning or seed priming. This technique has induced early and uniform germination of vegetables, soybean, cereals and forage grasses (Bodsworth and Bewley, 1981). PEG in aqueous solutions creates a negative water potential so seed will imbibe enough moisture to start the physiological changes necessary for germination, but will not actually germinate. Physiological repair processes such as restoration of membranes and mobilization of storage reserves are stimulated by priming (Knypl and Khan, 1981). Khan, et al., (1978) studied lettuce seed osmoconditioning

and found that it caused the activation and/or synthesis of enzymes used in the breakdown of proteins, lipids, and phosphate esters used in glycolysis.

There are several factors to consider when priming seed. Each species and possibly each seedlot within that species requires a different concentration of osmoticum, priming duration and priming temperature. Heydecker, et al.,(1973), found that with onion seed, a temperature of 10 C, a priming duration of 23 days and a potential of -10 bars gave the best results. Studies by Knypl and Khan (1981) showed 15 C, 4 to 8 days and -8.6 to -11.9 bars to be the optimum priming treatments for soybean. Bodsworth and Bewley (1981) reported optimum priming treatments of 10 C at -10 bars for six days; for maize, 10 C at -10 bars for 2 days; for wheat and barley, 10 C at -10 bars for 1 day; for sorghum, and 10 C at -5 bars for 6 days; for soybean. Abernathy (1986) reported variability among seedlots of Cicer milkvetch (*Astragalus cicer* L.)indicating the optimum osmoconditioning may need to be determined for each seed lot.

Seed Vigor Tests

Differences in "germination energy" or seed vigor was first observed by Nobbe (1876). The definition of seed vigor adopted by the Association of Official Seed Analysts (AOSA , 1983) is: "Seed vigor comprises those properties which determine the potential for rapid, uniform emergence

and development of normal seedlings under a wide range of field conditions".

The AOSA (1983) classifies seed vigor tests three ways: (1) seedling growth and evaluation tests, (2) stress tests, and (3) biochemical tests. Seedling growth and evaluation tests include seedling vigor classification and seedling growth rate tests. Accelerating aging test, cold test and cool germination tests are stress tests. Biochemical tests are tetrazolium and conductivity tests. There is no one test that is accepted as a standard for seed vigor. Each seed laboratory standardizes its own test procedures, but standardization among laboratories has been difficult.

The seedling vigor classification test divides normal seedling into strong and weak categories. The test was proposed for vigor assessment of soybean, cotton, peanut and green bean (Woodstock 1976). This test provides a means of separating seedlings free of deficiencies from those with deficiencies symptomatic of either low vigor or reduced quality. The seedling growth rate test was developed to obtain reproducibility in strong and weak classifications. Biochemical measurements and vegetative growth in the field have been correlated with seedling growth rate (AOSA, 1983).

The accelerated aging test stresses seed prior to germination. The basis for this test is that high vigor seed tolerates high temperature and humidity during storage better than low vigor seed. Delouche (1965) first developed

this test for predicting the relative storability of seeds, but now it is also used as a vigor test (AOSA, 1983).

Cool germination is a stress test to evaluate field condition effects. High vigor seed will perform better under adverse conditions than low vigor seeds (AOSA, 1983).

The tetrazolium test is essentially a measurement of dehydrogenase enzyme activity. Lakon (1942) first developed this technique for seed viability testing and later the staining patterns of the tissues were used to assess vigor (Moore and Goodsell 1965, Moore 1972). Living cells of a seed soaked in tetrazolium solution will stain red while dead cells remain colorless. Evaluation of the amount and placement of red color within the seed and turgidity of tissues are used to distinguish high vigor seed from low vigor seed (AOSA, 1983).

Measurement of electrolytes leaking from seed is the basis for the conductivity test. Dry seed loses membrane integrity, but, upon imbibition membranes are restored. However, before membranes are restored there is leakage of electrolytes. The vigorous seed more rapidly restores membrane integrity and exhibits less leakage of electrolytes. Conductivity tests have shown positive correlation with field emergence for field corn and soybean (Tao 1980).

CHAPTER III

STORAGE CONDITIONS

Introduction

Hardseededness in some legumes has long been recognized as being related to storage conditions with high temperature and low humidity favoring its development. Studies conducted by Frisbee, et al. (1987), indicated that hardseededness was significantly reduced with cool storage, when germinated at 5 C.

Chickpea seed exhibits very little hardseededness when germinated at optimum temperature (27 C), but when germinated at 5 C hardseededness increases. The 5 C germination temperature is similar to the field conditions of early planting of chickpea in Montana.

Studies were undertaken in 1985 and 1986 to determine if cool storage of chickpea improved field emergence and reduced hardseededness under cool soil conditions. The relationship between cool storage, seed moisture content, and hardseededness was evaluated.

Materials and Methods

A field study was conducted in 1985 using two desi seedlots of 'Garnet" chickpea, harvested in 1981 and 1983 at Pullman, Washington. Two field plantings were made, April 23

and May 21, to evaluate the effects of soil temperature on emergence. Soil temperature April 23 was 4 C, and 20 C on May 21.

Six storage conditions were used for the April planting and nine storage conditions were used for the May planting. Storage conditions used for the April planting were: 1) 1981 seed stored 36 months warm (room temperature), 2) 1981 seed stored warm for 35 months, then 1 month in cool (10 C, 50 % relative humidity) storage, 3) 1981 seed stored cool for 6 months, then warm for 1 month, 4) 1981 seed stored for 7 months cool, 5) 1983 seed stored for 17 months cool, then 1 month warm, and 6) 1983 seed stored for 18 months cool (Table 1).

The May planting had the following storage conditions: 1) 1981 seed stored for 36 months warm. 2) 1981 seed stored for 35 months warm, then 1 month cool, 3) 1981 seed stored for 34 months warm, then 2 months cool, 4) 1981 seed stored for 6 months cool, then 2 months warm, 5) 1981 seed stored for 7 months cool, then 1 month warm, 6) 1981 seed stored for 8 months cool. 7) 1983 seed stored for 16 months cool, then 2 months warm. 8) 1983 seed stored for 17 months cool, then 1 month warm. 9) 1983 seed stored for 18 months cool (Table 1).

Three weeks before planting, seed was treated with methyl 1-(butylcarbamoyl)-2-benzimidazolecarbamate (Benlate) at the rate of 3 gms ai per kilogram of seed to control

fungi (*Ascochyta*). One day before planting, approximately one gram of chickpea *Rhizobium* spp. innoculum was added to each packet of seed.

The field study was established near Manhattan, Montana on a Manhattan very fine, sandy-loam soil (coarse-loamy, mixed, Typic Calciborolls). This site received 14 cm of precipitation during April through August. A randomized block design with four replications was used with four rows, six meters long, spaced 0.3 meters apart. Three seeds were planted per linear foot at a depth of five cm.

Two center rows, one-half meter long, were used for emergence counts. Counts were taken daily for eight days beginning 12 days after planting, for the April planting. Daily emergence counts for the May planting were initiated seven days after planting and continued for 10 days, with a final count on the 15th day. One-half meter of the center two rows of each plot was hand harvested. The April planting was harvested on August 1 and the May planting was harvested on September 5. Harvested samples were cleaned using a belt thrasher and an aspirator. Samples were weighed to evaluate yield. Five hundred seeds were counted and weighed to determine seed size.

Germination tests were conducted to evaluate hard seed content. Four replications of fifty seeds each were placed in plastic germination boxes (4x14x13 cm) with two H_2O

saturated blotters. Boxes were placed in 5 and 27 C incubators. Germination counts were taken after one week for seeds in the 27 C germinator and after two weeks for those in the 5 C incubator.

Seed moisture content was measured by drying two replicates of 25 gm of seed at 100 C for 24 hours. Percentage moisture was determined on a wet-weight basis. Data were analyzed with the Plant and Soil Science Discovery computer system using "MSUSTAT" (Lund, 1983).

The 1986 field study was conducted similarily to the 1985 study with the following exceptions; seedlots were 1981 and 1985 'Garnet' chickpea from Pullman, Washington. The 1981 seedlot was stored for four years cool or for four years warm. The 1985 seedlot was stored for one year cool or warm. Field planting was made on May 1 at the Arthur H. Post field research laboratory near Bozeman, Montana. The soil at the field research laboratory is classified as an Amsterdam variant of silt loam (fine-silty, mixed family of Typic Haploborolls). Rainfall for the growing season was 25 cm. Daily emergence counts were taken 20 days after planting for 13 days, with a final count taken on the 19th day after emergence. Plots were infested with *Ascochyta* fungi in mid-season so seed harvest was not possible. Germination tests of the seed were conducted using six replications with 50 seeds per replication in a 5 C germinator. Germination

counts were made daily for three weeks and percentage germination and speed of germination were calculated.

Results and Discussion

The April, 1985 planting had significant differences in total emergence, but no differences in speed of emergence, yield and seed size. The best treatment was the 1981 seedlot, which was stored for seven months cool with a total seedling emergence of seven (Table 1). These results suggest that the 1981 seedlot is more responsive to warm or cool storage when planted under cool soil conditions.

The May, 1985 planting had significant differences in total emergence and seed size, with no differences in speed of emergence and yield. The highest total emergence resulted from the 1983 seedlot stored 18 months cool; 17 months cool, then 1 month warm; 16 months cool, then 2 months warm and the 1981 seedlot stored eight months cool. These seedlots had total emergences of 12, 11 and 9 respectively (Table 1). The 1981 seedlot stored for 36 months warm produced the smallest seeds (Table 1).

Four similar treatments from the early and late plantings were compared to determine the effects of soil temperature on emergence and yield. There were significant differences in total emergence for planting time and storage conditions (Table 2). The early planting had significantly

Table 1: Total emergence (TE), speed of emergence (EI), seed yield and seed size for early and late plantings of chickpea.

Months warm	Storage or cool	Seed-lot	TE (per meter row)	EI	Yield (Mg ha^{-1})	Seed Size (500 wt)
Early Planting (April 23)						
36 wm	0 cl	1981	3	.98	3.60	76.64
35 wm	1 cl	1981	4	1.23	3.91	77.09
6 cl	1 wm	1981	3	1.08	3.52	72.96
7 cl	0 wm	1981	7	2.25	4.13	69.85
17 cl	1 wm	1983	4	1.12	3.77	71.12
18 cl	0 wm	1983	4	1.25	3.91	71.65
LSD .05			2.5	NS	NS	NS
Late Planting (May 21)						
36 wm	0 cl	1981	8	2.79	2.80	73.20
35 wm	1 cl	1981	8	2.60	3.19	77.09
34 wm	2 cl	1981	6	2.06	2.94	77.37
6 cl	2 wm	1981	8	2.99	3.11	76.84
7 cl	1 wm	1981	8	2.30	3.07	76.90
8 cl	0 wm	1981	9	3.13	2.75	78.81
16 cl	2 wm	1983	11	2.81	3.32	79.53
17 cl	1 wm	1983	9	2.52	3.01	77.38
18 cl	0 wm	1983	12	4.29	3.11	78.56
LSD .05			3.3	NS	NS	2.96

fewer seedlings emerge than the late planting. Cool storage allowed more seedlings to emerge in the early planting than did warm storage. The storage conditions did not affect emergence at the late planting. The yield was significantly greater for the early planting even though more seedlings had emerged for the late planting (Table 2). Early plantings are necessary in Montana since chickpea needs a long growing season to produce maximum yield. Seed

size was significantly greater for the May planting, 78.30 gm per 500 seeds as compared to 73.74 gm per 500 seeds for the April planting (Table 2). However, when yields are higher, seed size is usually lower, as was the case with the early planting.

Table 2: Comparison of storage conditions, total emergence (TE), speed of emergence (EI), seed yield and seed size for 1985 early and late plantings.

Months warm	Storage or cool	Seed-lot	Plan-ting	TE (per meter row)	EI	Yield (Mg ha^{-1})	Seed Size 500wt
36 wm	0 cl	1981	early	3a	.99a	3.61a	73.22a
			late	7b	2.79b	2.80b	77.72b
35 wm	1 cl	1981	early	4a	1.24a	3.65a	72.70a
			late	8b	2.59b	3.19b	77.90b
8 cl	0 wm	1981	early	7a	2.25a	4.13a	75.97a
			late	9b	3.13b	2.75b	78.57b
17 cl	1 wm	1983	early	3a	1.00a	3.76a	73.07a
			late	9b	2.52b	3.01b	79.00b

Means followed by letters in common are not significantly different according to Tukey at the .05 level of probability.

Comparison of storage conditions averaged over early and late plantings showed significant difference in total emergence only, with the eight months cool storage treatment being significantly better in total emergence than the 36 month warm storage treatment (Table 3).

Germination tests of planted seed validated the field data indicating that cool storage increased germination percentage and decreased hard seed content (Table 4). It also

should be noted that the 1981 seedlot contained more hard seed than the 1983 seedlot.

Table 3: Comparison of storage conditions averaged over early and late plantings in 1985 for total emergence (TE), speed of emergence (EI), yield and seed size.

Months warm	Storage cool	Seed-lot	TE (per meter row)	EI	Yield Mg ha^{-1}	Seed Size 500 wt
36 wm	0 cl	1981	5a	1.89a	3.20a	75.47a
35 wm	1 cl	1981	6ab	1.91a	3.42a	75.30a
8 cl	0 wm	1981	8b	2.69a	3.44a	77.27a
17 cl	1 wm	1983	6ab	1.76a	3.39a	76.04a

Means followed by letters in common are not significantly different according to Tukey at the .05 level of probability.

Table 4: Percentage germination and hard seed for chickpea seed used in 1985 field study on storage conditions.

Months warm	Storage cool	Seed-lot	Percentage Germ	Hard
36 wm	0 cl	1981	70a	27c
35 wm	1 cl	1981	83b	10b
34 wm	2 cl	1981	91cb	5ab
6 cl	2 wm	1981	69a	21c
7 cl	1 wm	1981	69a	25c
8 cl	0 wm	1981	100c	0a
16 cl	2 wm	1983	94cb	2ab
17 cl	1 wm	1983	96c	1a
18 cl	0 wm	1983	97c	1a

Means followed by letters in common are not significantly different according to Tukey at the .05 level of probability.

The relationship between hardseededness and seed moisture content was evaluated. Four storage durations of 0,

4, 5 and 10 months cool storage were utilized. There were significant differences among treatments with 0 cool storage having 27 % hard seed and the 10 months cool storage having no hard seed (Table 5). Cool storage increased seed moisture content and decreased hard seed content. Regression analysis comparing percentage germination and seed moisture was significant at .92.

Table 5: Relationship between percentage hard seed and seed moisture content (SMC).

Months cool storage	Percentage		
	Germ	Hard	SMC
0	70a	27b	6.5a
4	91cb	5a	10.0ab
5	83b	10a	10.5b
10	100c	0a	10.5b

Means followed by letters in common are not significantly different according to Tukey at the .05 level of probability.

The 1986 field study had significant differences in total emergence and speed of emergence (Table 6). There was an interaction between seedlots and storage conditions for total emergence and emergence index (Fig. 1). The 1985 seedlot, stored warm or cool and the 1981 seedlot stored cool were significantly greater for total emergence and speed of emergence than the 1981 seedlot that was stored warm (Table 6).

The laboratory tests on these seedlots showed significant differences in percentage germination,

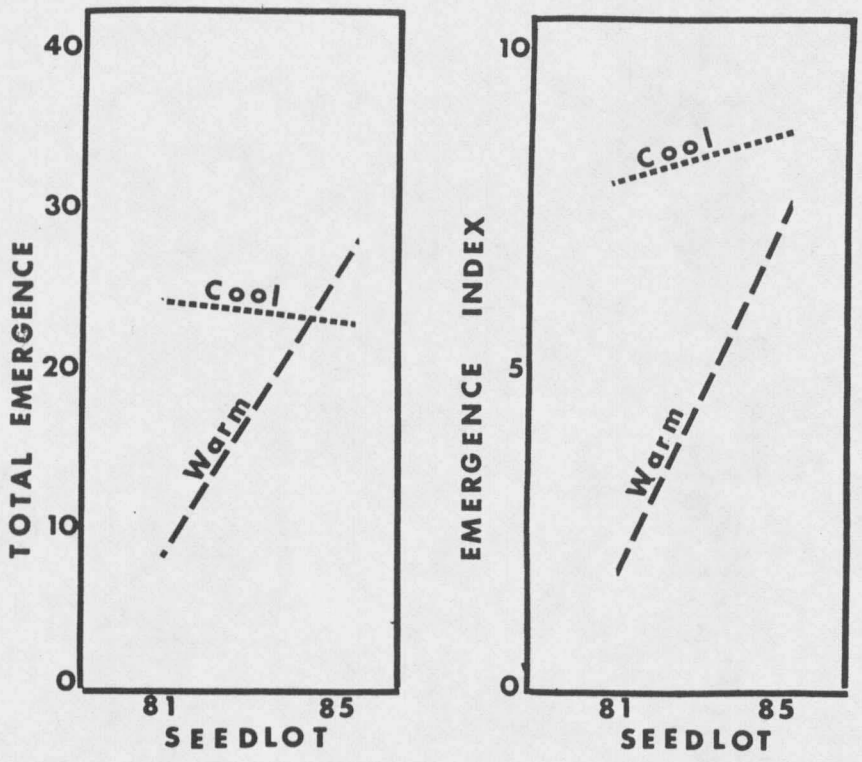

Figure 1: Interactions between storage conditions and seedlots for total emergence and emergence index.

percentage and seed and speed of germination. Additionally, there was an interaction between seedlots and storage conditions (Fig. 2). The two cool storage treatments (4 or 1 year cool) had the highest germination percentage and the lowest hard seed content, which was also associated with high moisture content. Correlation between percentage hard seed and seed moisture content was not significant. However, the 1985 seedlot receiving one year warm storage and the 1981 seedlot receiving 4 years cool storage had the highest speed of germination (Table 6).

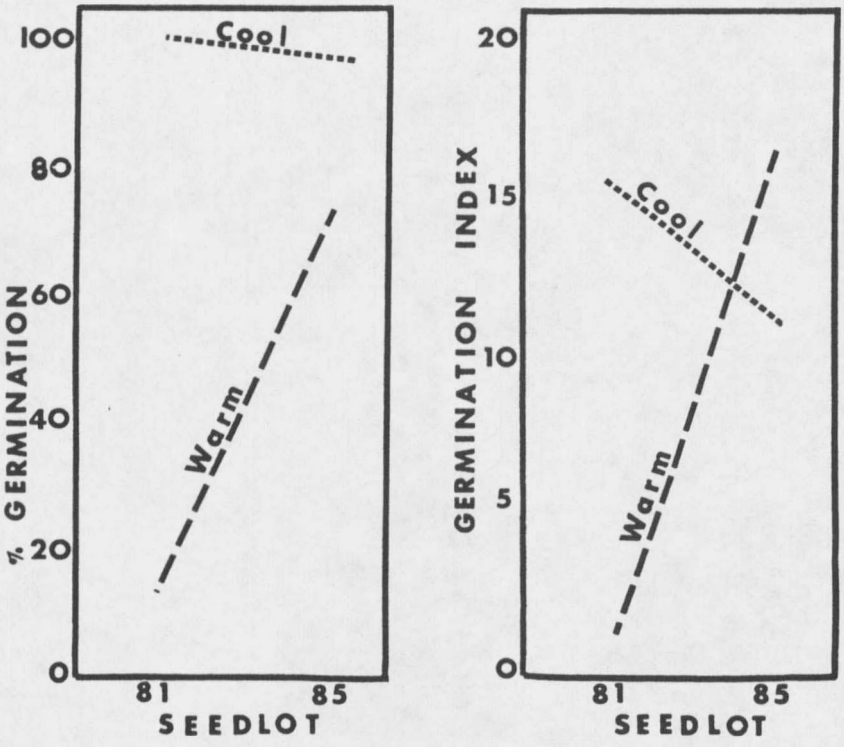

Figure 2: Interactions between storage conditions and seedlots for percentage germination and germination index.

Table 6: Total emergence (TE), speed of emergence (EI), percentage germination, percentage hard seed and speed of germination (GI) and seed moisture content (SMC) for 1986 field and laboratory study on storage conditions.

Storage	Seedlot	TE (per meter row)	EI	% Germ	% Hard	GI	% SMC
4 yrs wm	1981	10a	1.93a	15a	82c	1.01a	5a
1 yr wm	1985	26b	7.32b	70b	27b	15.97c	6a
4 yrs cl	1981	24b	8.03b	100c	0a	15.37c	10b
1 yr cl	1985	23b	8.65b	97c	1a	11.00b	10b

Means followed by letters in common are not significantly different according to Tukey at the .05 level of probability.

Total emergence and the speed of emergence for the 1985 seedlot did not improve with cool storage, whereas there was a considerable improvement of cool storage over warm storage for the 1981 seedlot (Fig. 1).

CHAPTER IV

SEED MOISTURE

Introduction

The relationship between relative humidity and temperature affects legume seed moisture content. Several researchers have reported that percentage of hard seed in legumes is directly related to seed moisture content. Harrington (1949) found that dry bean (*Phaseolus vulgaris* L.) seed moisture content was determined by the relative humidity exposure time. Hard seed content increased as moisture content decreased. Lebedeff (1943) reported that the drying of dry bean seed with calcium chloride increased hard seed number as moisture content declined. Nakamara (1962) noted the same relative humidity, seed moisture and hard seed relationship for milkvetch (*Astragalus sinicus* L.) and alfalfa (*Medicago sativa* L.).

This study was conducted to determine the relationship among relative humidity, seed moisture and hardseededness of chickpea (*Cicer arietinum* L.), since hardseededness is a problem when this crop is planted into cool soils.

Materials and Methods

Desi-type 'Garnet' chickpea seed, grown in 1981 at Pullman, Washington was evaluated under five relative

humidity regimes ranging from 10 - 100 %. Treatments consisted of ZnCl, KCO_3, $NaNO_2$, KNO_3 and a water control. These treatments were to produce relative humidities of 10, 47, 66, 96 and 100 % respectively (Gladstones, 1958). The chemicals used to induce the RH treatments were contained in 50 ml beakers, which were and placed in the center of one quart jars with 68 gm of chickpea seed. Nine jars for each RH treatment were tightly sealed and incubated at 5 and 25 C.

One jar per treatment per replication was removed after 3 weeks of storage to determine seed moisture. Seed moistures was determined on a wet-weight basis utilizing two 25 gm seed replicates dried at 100 C for 24 hours. The procedure was repeated weekly for seven weeks until a 6 % seed moisture content was reached for both storage regimes. One jar from each temperature treatment at 6 % seed moisture was removed to determine the percentage germination of seeds stored at 5 and 25 C.

Six replications of fifty seeds were germinated in plastic boxes (4x14x13 cm), containing two water saturated blotters. Treatments were evaluated at three week intervals to determine percentage germination and hard seed.

A growth chamber study utilizing, six plastic flats (30x38x10 cm) filled with standard greenhouse soil mix, was conducted for comparison with the germination tests. Fifty seeds per treatment at 6 % moisture content (original

storage study) were planted 5 cm deep and 1.25 cm apart in four rows. The flats were then placed in a growth chamber at 5 C for six seeks. Water was added to each flat as needed to maintain soil moisture. Percentage emergence, emergence index (speed of emergence) and seedling weight were determined. Emergence index was calculated using Maguires formula (Maguire, 1962). Seedling weight was determined by cutting plants at the soil surface and drying at 100 C for 24 hours.

Data were analyzed with the Plant and Soil Science Discovery Computer System using "MSUSTAT" (Lund, 1983).

Results and Discussion

The highest seed moisture (19.8 %) was obtained at the 25 C storage temperature at 96 % RH (Fig. 3). The highest seed moisture obtained under 5 C storage and 96 % RH was 8 %. The percentage germination of the seed with 8 % moisture, germinated and stored at 5 C was 59 % as compared to 96 % for the same treatment stored at 25 C. When seed moisture was 6 % for both storage temperatures (5 and 25 C) and seeds were germinated at 5 C, the percentage germination was 54 % for the 5 C storate and 81 % for the 25 C storage condition. The 25 C storage condition had the least hard seed and the highest germination (Fig. 4).

Percentage emergence and seedling weight were both improved when seeds were stored at 25 C (Fig. 5). Percentage

emergence of seed stored at 5 C was 38 % compared to 81 % emergence when stored at 25 C. The mean seedling weight at 5 and 25 C storage was 0.69 and 1.19 gm, respectively (Fig. 5). Emergence index for all treatments was non-significant.

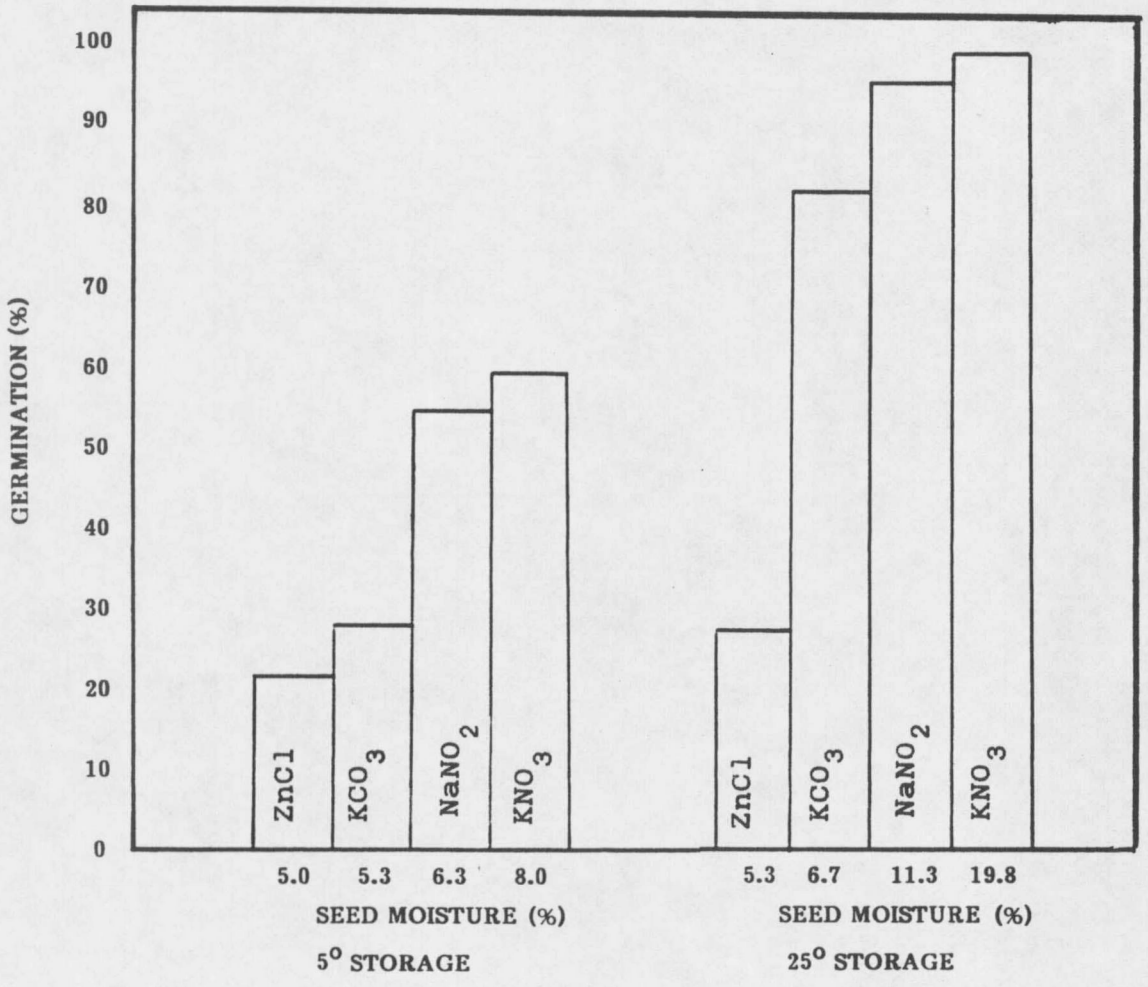

Figure 3: Percentage germination for various 'Garnet' chickpea seed moisture contents when stored at temperatures of 5 and 25 C. Germinated at 5 C.

There was an interaction between the two storage temperatures at 6 % seed moisture (Fig. 6). Percentage germi-

nation appeared to be associated with moisture content when stored at both temperatures. Seeds stored at 5 C failed to reach as high a moisture content as expected. The 5 C storage treatment may have altered seed coat permeability and prevented water uptake.

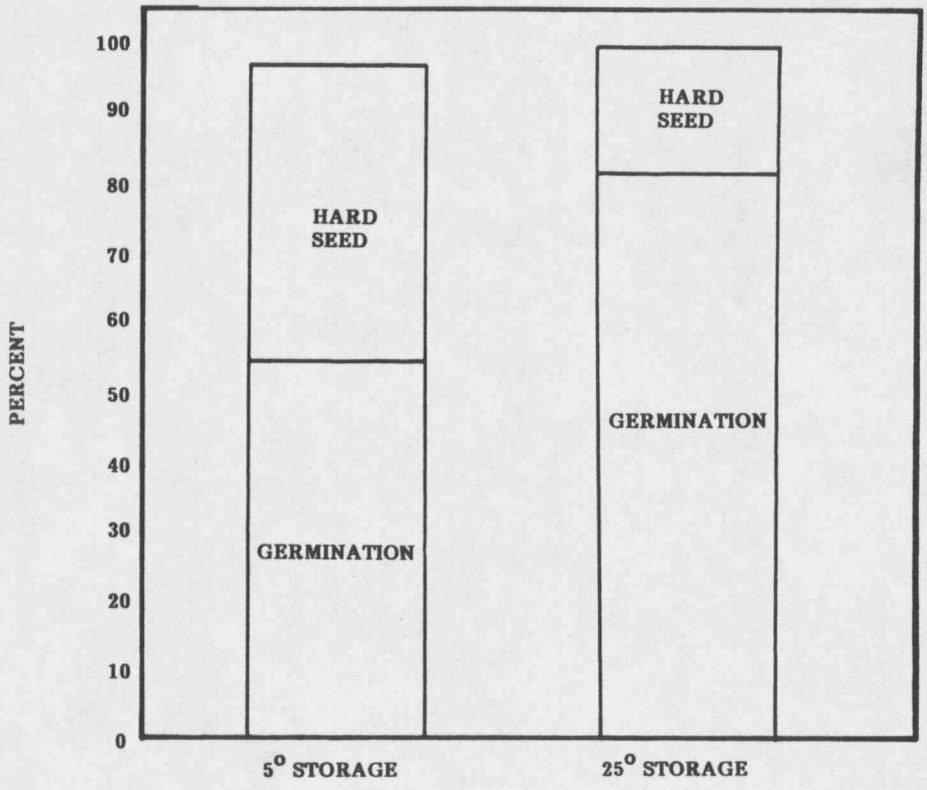

Figure 4: Effects of 5 and 25 C storage temperatures on hardseedness and germination of 'Garnet' chickpea seed with 6 % moisture (germinated at 5 C).

Results of these experiments indicated that high moisture content may reduce hardseededness in 'Garnet' chickpea more effectively than storage temperature. However, further research is needed utilizing more seed lots and varieties under a greater range of environmental conditions.

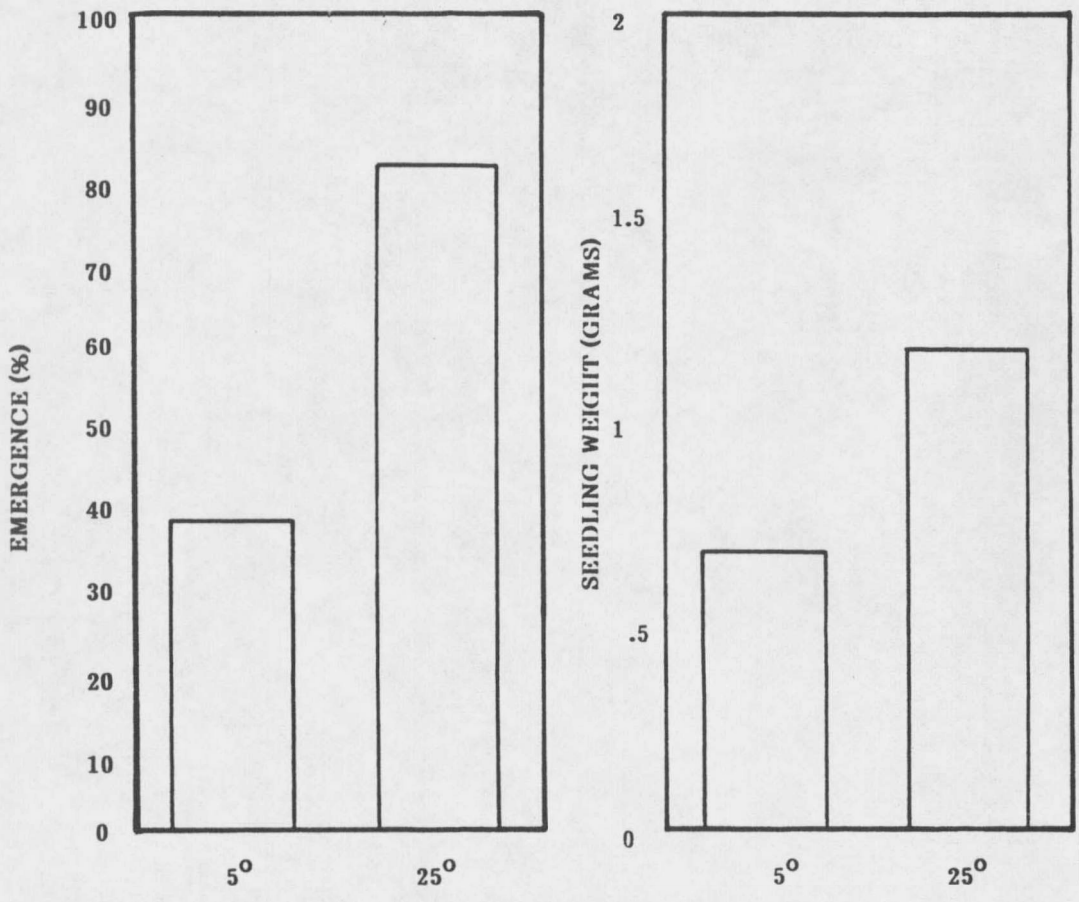

Figure 5: Effects of 5 and 25 C storage temperatures on emergence and seedling weight when 'Garnet' chickpea seed moisutre was approximately 6 %. Conducted in a growth chamber at 5 C for six weeks.

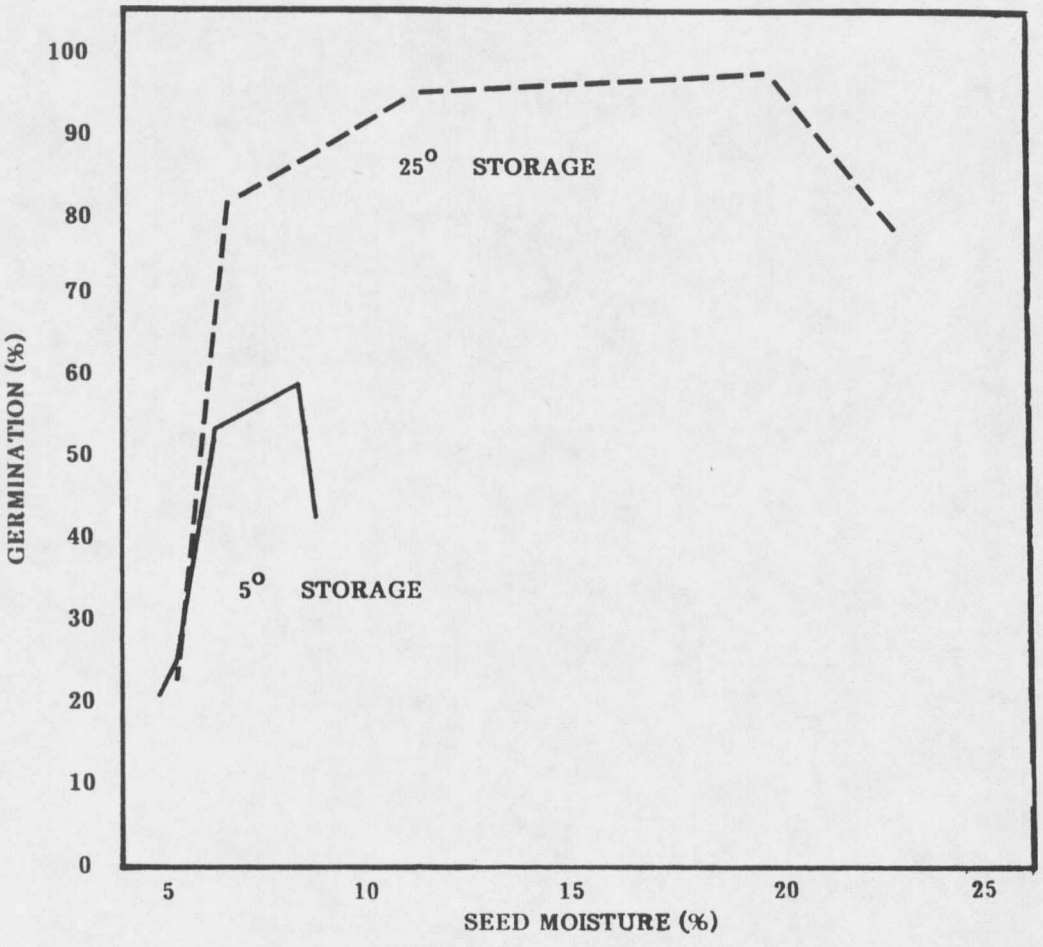

Figure 6: Effects of seed moisture and storage temperature on 'Garnet' chickpea germination at 5 C.

CHAPTER V

SEED PRIMING

Introduction

Seed priming, using polyethylene glycol (PEG), was first studied by Heydecker, et al., (1973). They found that the imbibition of seed in this osmoticum induced early and uniform germination of onion seed. Researchers have since reported similar results with other crop species; cicer milkvetch (Abernathy, 1986); maize, wheat, barley, sorghum and soybean (Bodsworth and Bewley, 1981); lettuce (Khan, et al., 1978); soybean (Knypl and Khan, 1981). Akalehiywot and Bewley (1977) reported that priming with PEG solutions enables seeds to germinate at temperatures lower than those at which untreated seeds will germinate. PEG solutions allow the seed to take up enough moisture to begin the physiological processes necessary for germination, but not enough for actual germination. Priming could reduce the exposure of seeds to suboptimal growing conditions of cool soils and could improve crop stands. Chickpea is planted in early spring in Montana to ensure an adequate growing season. Planting chickpea in cool soil increases hard seed content, therefore, reducing stand establishment.

Studies were undertaken to determine the optimal priming temperature, priming duration and osmotic potential

for chickpea. Percentage germination and percentage hard seed, speed of germination and seed moisture were also evaluated.

Materials and Methods

'Garnet' desi-type chickpea seed grown at Pullman Washington in 1981 was used for this study. Three priming temperatures of 10, 15 and 20 C; three priming durations of 4, 6 and 8 days and three osmotic potentials of -1.5, -3 and -5 bars were chosen based on previous reports of Akaleiywot and Bewley (1977) and on preliminary studies. Osmotic potentials were calculated according to Michel and Kaufman (1973). PEG (8000) from J. T. Baker Chemical Co.* was used. Seeds were primed in plastic boxes (4x14x13 cm) containing two germination blotters saturated with approximately 40 ml of osmoticum. Thirty-six gm of seed were placed in each box. Six replications of 50 primed seeds per treatment were germinated at 5 C in plastic boxes (4x14x13 cm), containing two water saturated germination blotters. Germination counts were taken daily and the following parameters determined; percentage germination and hard seed, speed of germination and seed moisture. Seed moisture was determined on a wet-weight basis by drying two replicates of 25 gm of seed at 100 C for 24 hours.

*Use of a trade name does not necessarily mean a recommendation.

Results and Discussion

There was no significant difference among the three osmotic potentials used, but there was a significant difference between priming and no priming (Table 7).

Table 7: Percentage germination, hard seed content, seed moisture content (SMC) and speed of germination (GI) for chickpea using three different potentials averaged over priming durations of 4, 6, and 8 days and three priming temperatures of 10, 15 and 20 C.

	Percentage			
Potential	Germ	Hard	SMC	GI
-1.5 bars	62b	29a	21b	7.09b
-3.0 bars	62b	29a	20b	6.85b
-5.0 bars	63b	29a	20b	6.58b
Unprimed	26a	66b	6a	1.69a

Means followed by letters in common are not sig-significantly different according to Tukey at the .05 level of significance.

The two treatments; 15 C, -5 bars, 8 day and the 20 C, -5 bars, 8 day, had the highest germination, 84 and 77 %, and the lowest hard seed content, 12 and 17 % respectively. The germination rate for unprimed seed was 26 %, and the hard seed content was 66 % (Table 8). The highest germination index was reached with 15 C, -5 bars, 8 day, increasing the index from 1.69 for unprimed to 10.72 for primed. Seed moisture was increased from 6 to 27 % with priming (Table 8). There was a significant correlation between seed moisture and hard seed.

Table 8: Percentage germination and hard seed, speed of germination (GI) and seed moisture content (SMC) for chickpea primed with PEG at -5 bars.

Temperature	Duration in days	Percentage Germ	Hard	SMC	GI
10C	4	43b	49d	18bc	4.14b
	6	54c	36c	16b	5.64bc
	8	60cd	33c	17b	6.51c
15C	4	55c	37c	18b	5.69bc
	6	56cd	32c	22cd	6.00bc
	8	77ef	17a	27e	10.72e
20C	4	65d	30bc	17b	5.79bc
	6	75e	20ab	19bc	6.25c
	8	84f	12a	25ed	8.49d
Unprimed		26a	66e	6a	1.69a

Means followed by letters in common are not significantly different according to Tukey at the .05 level of significance.

It appears that, priming of desi-type chickpea seed could increase percentage field emergence and speed of emergence in cool soils. The major effect of seed priming is an increase in seed moisture, which decreases hard seed and increases the speed of germination.

CHAPTER VI

LOCATION

Introduction

The hardseededness of many legumes is affected by the environmental conditions of the growing season. High soil moisture during seed fill reduced hard seed in soybean (*Glysine max* L.) (Hill, 1986). Quinlivan (1965), has reported that soil moisture stress during maturation caused fewer hard seeds in subterranean clover (*Trifolium subterraneum* L.) However, a long growing period in the spring caused more hard seed in subterranean clover. A warm environment during flowering and seed formation produced more hard seed in carribean stylo (*Stylosanthes hamata* (L.) Taub. cv. Verano) (Argel and Humphreys, 1983). In alfalfa (*Medicago sativa* L.), low temperatures during maturation caused more hard seed (Gunn, 1972). In some legumes, dry air during maturation produced more hard seed (Bewley and Black, 1985).

The purpose of this study was to determine if the location where chickpea was grown affects the degree of hardseededness.

Materials and Methods

Desi-type 'Garnet' chickpea seed produced in 1981 in Pullman, Washington was grown at three locations: Pullman, Washington on a dryland site, Lind, Washington on an irrigated site and Manhattan, Montana on a dryland site.

Seeds were sent to Bozeman, Montana after harvest for evaluation. Seed moisture was determined on a wet-weight basis. Percentage germination and hard seed were determined by germination tests using six replications of fifty seeds in plastic boxes (4x14x13 cm) containing water saturated blotters. Seeds were germinated at 5 C and germination and hard seed counts were taken after three weeks. Seed size was determined by weighing four replications of 500 seeds for each location.

Weather information was obtained from the National Climatic Data Center, Asheville, North Carolina (National Oceanic and Atmospheric Administration, 1985) for Washington and from a weather station located on the John Schutter farm for the Montana grown chickpea (Hicks, 1986) (Table 9).

Data were analyzed with the Plant and Soil Science Discovery Computer System using "MSUSTAT" (Lund, 1983).

Table 9: Average high and low temperature (C) and average amount of precipatation (mm), May through August, 1985, for Pullman and Lind, Wa. and Manhattan, Mt.

	Pullman			Lind			Manhattan		
Month	Precip (mm)	Temp(C) H	L	Precip (mm)	Temp(C) H	L	Precip (mm)	Temp(C) H	L
May	30.0	20	6	5.6	25	5	71.0	20	4
June	39.4	23	7	14.5	28	8	17.0	23	8
July	2.3	32	11	T	38	13	11.0	29	11
August	30.7	26	9	20.0	30	10	40.5	24	8

Results and Discussion

The Pullman, Washington dryland site produced the highest hard seed content (47 %) and the Manhattan, Montana dryland site had the lowest hard seed content (4 %) (Table 10). There was no significant difference in the hard seed content of the Manhattan, MT seedlot and the seed produced at Lind, Wa. There was no significant difference in

Table 10: Percentage germination, hard seed, seed moisture content (SMC) and seed size (500 wt) for Pullman and Lind, Washington and Manhattan, Montana, 1985.

Location	Percentage Germ	Hard	SMC	500wt
Pullman (dryland)	40a	47b	5a	80.97a
Lind (irrigated)	74a	14a	6a	95.20b
Manhattan (dryland)	87c	4a	7a	81.92a

Means followed by letters in common are not significantly different according to Tukey at the .05 level of significance.

seed moisture among seedlots. The largest seed size, 95.2 gm^{-1} 500 seeds, was produced at the Pullman dryland site. The low hard seed content at the Manhattan dryland site could be a result of a short growing period in the spring, low soil moisture during maturation, low temperature during flowering and seed formation or because the seed were harvested before they were fully mature. The high hard seed content at the Pullman dryland site could be a result of later harvest where seed had an opportunity to mature. There was a significant difference in seed size between the Pullman and the Manhattan dryland site, indicating that the seed at the Manhattan site was harvested before they were mature. Additionally the 47 % hard seed content of the Pullman location indicated a longer maturation period.

Hardseededness varied by location for chickpea. However, it was difficult to determine which environmental factor increased or decreased hard seed content. Further research is needed to deliniate which environmental factors influenced hardseededness.

CHAPTER VII

SEED VIGOR

Introduction

The value of seed vigor tests has become evident as seed producers have realized the importance of high vigor seed in crop production. There has been a great increase in the number of seed vigor tests and their uses in the last 20 years.

A measurement of seed deterioration or genetic deficiency must be used to determine seed vigor. The degree of deterioration or the seriousness of the genetic deficiency is inversely proportional to the vigor of the seed (AOSA, 1983).

A series of seed vigor tests and a correlating greenhouse study were conducted. Eight seedlots of kabuli type chickpea grown in the Palouse area of Washington and Idaho were evaluated to determine if seed vigor tests could be used to predict seed performance. It was necessary to develop a seed treatment to control fungi before the seed vigor tests could be conducted.

Materials and Methods

General

The eight seedlots of kabuli-type chickpea that were used for the fungi study and all seed vigor tests were:

#1 - CP8 Genesee, Id. 1982

#2 - CP8 Farmington, Wa. 1984

#3 - CP8 Pullman, Wa. 1984

#4 - CP8 Genesee, Id. 1984

#5 - ILC591 Lind, Wa. (dryland) 1985

#6 - ILC591 Lind, Wa. (irrigated) 1985

#7 - ILC171 Lind, Wa. (dryland) 1985

#8 - ILC171 Lind, Wa. (irrigated) 1985

All germination tests were conducted in plastic germination boxes (4x14x13 cm), containing two water saturated germination blotters. A seed was considered germinated when the radical emerged. Germination index (speed of germination) and Emergence Index (speed of emergence) was calculated using Maguire's formula (Maguire, 1962).

Fungi

Seeds were treated with four rates of Imazalil (0, .42, .63 and .84 oz cwt), four rates of diCloran (0, 300, 450, 600 ppm) and nine combinations of the aforementioned rates of Imazalil and diCloran. The seedling growth rate test (see below) was utilized for determining

effectiveness of each treatment. Percentage infection, dead seed, normal and abnormal seedlings were determined.

Seed Vigor and Germination Tests

Germination and speed of germination tests were conducted as previously stated. Seeds were germinated at 5 and 25 C using six replications of 50 seeds from each seedlot.

The seedling growth rate test was conducted by using four replications of 30 seeds for each seedlot. An eight cm layer of 76 weight paper towels, 25.4 x 40.6 cm, was saturated with water and pressed firmly on top of a 2.5 cm layer of dry towels. The layers were allowed to equilibrate one-half hour before planting, to ensure uniform moisture content. Seeds were placed between two moist paper towels, in two rows approximately 5 cm apart. The towels were then rolled loosely and secured at the bottom of the roll with a rubber band and placed in a container. Four rolls were placed in each container and covered with a plastic bag. The containers were then placed in a 25 C germinator for seven days. Normal and abnormal seedlings and dead seeds were counted at the end of the germination period. Normal seedlings were excised from the seed, put in coin envelopes and dried at 100 C for 24 hours and dried. The seedling dry weight was divided by the number of normal seedlings to determine the seedling growth rate (SGR).

For the conductivity test, four replicates of 25 seeds were weighed and placed in 115 ml of doubly deionized water for 24 hours at 20 C. All seedlots contained 7 % seed moisture before testing. Readings were taken with a Selectro Mark Analyzer (model 4503) conductivity meter. Each flask containing 25 seeds was gently shaken, then the dip cell was lowered 1 1/2 inches into the flask. Conductivity rating was obtained by dividing the reading (umhos) by the weight of seed (gm).

The accelarated aging test utilized fifty gm of seed, one layer deep, on a wire mesh tray, which was placed into a plastic germination box (11x11x3.5 cm) containing 40 ml of water. Seeds had been pretreated with .42 oz cwt Imazalil and 600 ppm diCloran to control fungi. The boxes were sealed and placed into the accelerated aging chamber at 41 C and 100 % RH humidity for 48 hours. Boxes were then removed and four replications of 50 seeds were germinated at 25 C, according to standard germination test (see above). All seedlots had 7 % seed moisture before the test was conducted.

Greenhouse Study

The greenhouse study was conducted utilizing metal flats (51x36x9 cm) filled with a standard greenhouse soil mix, containing 1/3 sand, 1/3 soil and 1/3 peat. Seven seedlots were used in this study, as lot 4 did not have sufficient seed for planting in the greenhouse. One seedlot

was planted per flat. Each flat contained four rows and nine seed were planted per row. The study was replicated six times. Temperature in the greenhouse was maintained at 68 C and supplemental light was provided for 12 hours per day. Flats were allowed to dry out between watering to stress the chickpea seedlings. Daily emergence counts were taken to determine percentage germination and speed of emergence. Six weeks after planting, seedlings were counted, cut at the soil surface, dryed for 36 hours at 100 C and weighed. Seedling growth rate (SGR) was determined as previously explained for the seedling growth rate vigor test.

Results and Discussion

Fungi Control

All seedlots used were infected to some degree with three types of fungi; *Rhizopus* spp.,*Aspergillus* spp. and *Penicillium spp.* Several treatments were used to control fungi during the germination and seedling growth rate tests. Preliminary studies indicated that Thiram, Captan, ammonium and sodium lauryl sulfate (shampoo), sodium hypochlorite (household bleach), and ethanol did not give sufficient control of fungi. Benlate was moderately successful when used with the germination and seedling growth rate tests. The combination of .42 oz cwt Imazalil and 600 ppm diChloran per 50 gm of seed was the best fungicide treatment. This

treatment resulted in a low percentage of infection (13 %), one of the highest percentage germinations (79 %) and one of the highest seedling growth rates (25.07) (Table 11). Imazalil controlled *Aspergillus* spp. and *Penicillium* spp.,

Table 11: Percentage Infection, Normal and Abnormal Seedlings, Dead Seed and Seedling Growth Rate (SGR) when treated with Imazlil and diChloran.

	Percentage				
Treatment	Infected	Normal	Abnormal	Dead Seed	SGR
Imazalil					
.42oz	57bcd	77ab	20a	3ab	29.00de
.63oz	73cd	61ab	29a	10ab	21.70abcd
.84oz	85cd	49a	33a	18b	29.30e
diChloran					
300 ppm	44abc	78b	20a	2ab	28.83cde
450 ppm	44abc	80b	11a	9ab	25.47abcde
600 ppm	23ab	81b	19a	1a	27.87bcde
Imazalil + diChloran					
.42oz+300ppm	11ab	74ab	24a	1a	21.43abc
.42oz+450ppm	14ab	77ab	20a	3ab	25.37abcde
.42oz+600ppm	13ab	79b	20a	1a	25.07abcde
.63oz+300ppm	12ab	73ab	25a	1a	28.93cde
.63oz+450ppm	11ab	61ab	34a	4ab	25.10abcde
.63oz+600ppm	19ab	67ab	32a	1a	27.17bcde
.84oz+300ppm	12ab	65ab	33a	1a	24.17abcde
.84oz+450ppm	17ab	53ab	38a	9ab	19.50a
.84oz+600ppm	6a	61ab	34a	4ab	21.17ab
Untreated	100f	60ab	25a	14ab	29.00dc

Means within columns followed by letters in common are not significantly different according to Tukey at the .05 level of probability.

while diChloran controlled *Rhizopus* spp. There was a synergistic effect for percentage infection, when the two fungi-

cides were used together. The higher rates of Imazalil increased infection, while the higher rates of diChloran did not affect infection significantly, but when Imazalil and diChloran were used together, the amount of infection dropped for all combinations. There was no synergistic effect for the other parameters.

Seed Germination (27C)

Seedlot 7 had the highest percentage germination (99 %), although it was not significantly different from all other seedlots except seedlot 1 (Table 12). The germination test under favorable temperatures gives objective, reproducible results and allows for evaluation of the potential viability of a seedlot. The test does not give an evaluation of how that seed will perform under field conditions, since the seed is not stressed. The germination test at 27 C was conducted for comparison with seed vigor tests and the greenhouse study.

Seed Vigor Tests

Speed of Germination (27C). Seedlot 7 had the greatest speed of germination (GI) (35.1), but was not significantly different from seedlots 3, 5, 6 and 8. (Table 12). This test indicated that seedlot 7 is the most vigorous and seedlot 1 the least vigorous.

Cool Germination Test (5C). Cool germination test results indicated that seedlots 5 and 6 are more vigorous with a percentage germination of 96 and 93 %, and GI's of 4.8 and 4.7 respectively. However, the two seedlots which had the highest warm temperature germination (1 and 7) had the poorest cool temperature percentage germinations (76 and 80 %) and the lowest GI's (3.5 and 3.3) respectively (Table 13).

Table 12: Percentage germination and Germination Index (GI) at 27 C.

Seedlot	% Germ	GI
1	90a	19.8ab
2	97ab	16.2a
3	97b	26.1abc
4	94ab	16.8a
5	97ab	29.1abc
6	92ab	31.3bc
7	99b	35.1c
8	97b	26.8abc

Means followed by letters in common are not significantly different according to Tukey at the .05 level of probability.

Cool germination is a stress test to simulate field conditions. High vigor seeds should perform better under adverse conditions than low vigor seeds. This vigor test should relate better to chickpea planting conditions than germination at 27 C and therefore predict field performance.

Seedling Growth Rate. Seedling growth rate test (SGR) results indicated that seedlot 6 had the highest percentage

germination (85 %) when exposed to a moisture stress, but was not significantly different from all other seedlots, except 1 (Table 14). Percentage germination for the cool germination test for all seedlots was 10 to 20 % more than the percentage germination

Table 13: Percentage germination and Germination Index for Cool Germination Test (5 C).

Seedlot	% Germ	GI
1	76a	3.5a
2	80a	4.0ab
3	84abc	4.5ab
4	80a	3.7ab
5	96c	4.8b
6	93bc	4.7b
7	80a	3.3a
8	82ab	3.7ab

Means followed by letters in common are not significantly different according to Tukey at the .05 level of probability.

for the SGR test. This could be due to the moisture stress imposed on the SGR test. There was no significant difference in percentage germination with a optimum temperature of 27 C, except for lot 1. More differences in percentage germination occured between seedlots when seeds were put under temperature and moisture stress.

Seedlot 4 had the highest SGR (45.76 mg seedling^{-1}), although it was not significantly different from other seed lots, except for 5 and 8, which had SGR's of 38.13 and 40.33, respectively (Table 14).

The seedling growth rate test was developed to obtain reproducibility of strong and weak classifications. Biochemical measures and vegetative growth in the field are often correlated with seedling growth rate.

Table 14: Percentage germination and weight per seedling (SGR) for Seedling Growth Rate Test.

Seedlot	% Germ	SGR (mg seedling^{-1})
1	53a	44.50bc
2	64ab	44.55bc
3	66ab	44.27bc
4	67ab	45.76c
5	72ab	38.13a
6	85b	43.30bc
7	73ab	42.15abc
8	82b	40.33ab

Means followed by letters in common are not significantly different according to Tukey at the .05 level of probability.

Conductivity Test. Results of the conductivity test indicated that seedlot 7 was the most vigorous, but it was not significantly different from lots 5, 4, and 2. Seedlot 1 was the least vigorous with a reading of 57.9, but it was not significantly different from seedlots 2, 3, 4, 6 and 8. This test did not separate seedlots very well for vigor (Table 15).

Measurement of electrolytes leaking from a seed is the basis for the conductivity test. Dry seeds lose membrane integrity but membranes are restored upon imbibition. However, before membranes are restored there is leakage of

electrolytes. The more vigorous the seed the faster membrane integrity is restored and the less leakage of electrolytes. Conductivity tests have shown positive correlation with field emergence for field corn and soybean (Tao, 1980).

Table 15: Conductivity readings for Conductivity Test

Seedlot	Conductivity (umhos/gm)
1	57.9 c
2	48.3 abc
3	54.7 bc
4	50.3 abc
5	44.7 ab
6	50.9 bc
7	38.6 a
8	52.6 bc

Means followed by letters in common are not significantly different according to Tukey at the .05 level of probability.

Accelerating Aging Test. Results of the accelerating aging test show seedlots 5 and 7, with a germination rate of 97 %, as being the most vigorous, however, they were not significantly different from lots 8 and 4. Seedlot 1 was the least vigorous, having a germination rate of 29 % (Table 16). This test gave good separation of seedlots with a range of 29 to 97 % germination. It appears that the procedures used for this test are adaquate for testing of chickpea.

The accelerating aging test exposes seed to a high temperature (41 C) and high humidity (100 %). Under these conditions rate of deterioration is greatly increased. High vigor seeds will show only small decreases in germination

following accelerated aging while low vigor seeds will show marked decreases. Delouche and Baskin (1973) suggested that the germination response after accelerated aging was related to the performance of a seedlot in the field under a wide range of environmental conditions.

Table 16: Percentage germination following incubation in an Accelerating Aging Chamber.

Seedlot	% Germination
1	29 a
2	70 bc
3	55 b
4	78 cd
5	97 d
6	73 bc
7	97 d
8	85 cd

Means followed by letters in common are not significantly different according to Tukey at the .05 level of probability.

Greenhouse Study. A greenhouse study was conducted in conjunction with the seed vigor evaluations to determine which tests were the most predictive of kabuli type chickpea vigor. Results of the greenhouse study indicated that seedlots 5 and 7 had the highest percentage emergence and for that parameter were the most vigorous (Table 17). Seedlots 1 and 3 had the poorest emergence. There were no significant differences in emergence index or seedling growth rate.

Regression analysis indicated that percentage emergence in the greenhouse was correlated with accelerating aging and

electrical conductivity, with R-values of .93 and .85, respectively. The R-value was only improved to .94 when conductivity and accelerating aging results were regressed against percentage emergence. This indicates that accelerating aging was the best predictor of percentage emergence in the greenhouse.

Table 17: Percentage emergence, speed of emergence (EI) and seedling growth rate (SGR) for greenhouse study.

Seedlot	% Emer	EI	SGR (mg seedling^{-1})
1	77a	4.67a	269a
2	87ab	5.43a	300a
3	78a	6.00a	282a
5	92b	6.34a	231a
6	84ab	6.00a	233a
7	91b	5.60a	233a
8	88ab	6.28a	260a

Means followed by letters in common are not significantly different according to Tukey at the .05 level of probability.

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Bollinger, Shirley A.
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