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THESIS – THÈSE

Title of Thesis – Titre de la thèse

A Study of the Germination Requirements of 58 Forb Species Native to Southern Alberta

Degree for which thesis was presented
Grade pour lequel cette thèse fut présentée

MSc

Year this degree conferred
Année d'obtention de ce grade

1985

University – Université

University of Alberta

Name of Supervisor – Nom du directeur de thèse

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A study of the germination requirements of 58 forb species native to southern Alberta.

by

Elizabeth Ann Smreciu

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF Master of Science

DEPARTMENT OF PLANT SCIENCE

EDMONTON, ALBERTA

SPRING 1985

THE UNIVERSITY OF ALBERTA

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ABSTRACT

The germination potential of 58 wildflower species was studied to determine which, if any, have potential for mass production for replanting and restoration programs. The effect of pretreatments (specifically cold stratification and scarification) was determined and related to dormancy type. For 5 species (*Besseya wyomingensis*, *Lithospermum ruderale*, *Opuntia polyacantha*, *Penstemon nitidus*, and *Zizia aptera*), the anatomy of the seed coat or pericarp was studied. Two commonly used tests (i.e. tetrazolium staining and x-ray photography) were employed to determine seed viability.

Tetrazolium staining was an effective test for viability. Although staining was found to be erratic in some seed lots, viability could be determined by observing the extent and degree of stain and/or by examining embryos to determine if they were firm and healthy looking. X-ray photography was rapid and effective, especially for larger seeded species. Some difficulty was encountered when using it with very small seeds.

Most species demonstrated at least one type of organic dormancy. Thirteen species had impermeable seed coats; a condition which was effectively overcome by mechanical scarification. Germination of 27 species (including two with impermeable seed coats) improved if seeds were cold stratified. This was demonstrated by an increase in germination percentages. Pretreatments were unnecessary for

germination of 12 species.

Most species of the families Compositae, Scrophulariaceae, and Cactaceae germinated best if stratified whereas those of Ranunculaceae and Rosaceae required no pretreatment. Seeds of most members of the Leguminosae were exogenously dormant, and required scarification for prompt, uniform germination. Reaction of Liliaceae species to pretreatments varied. *Yucca glauca* germinated well with or without treatment. *Allium* species germinated best if scarified but for one (*Allium textile*), stratification in combination with scarification was the most effective treatment. Germination of *Smilacina stellata* improved with cold stratification.

Germination of over 60% was obtained for seeds lots of 42 species. These species should present no problems for production of large numbers of seedling plants. Maximum germination obtained for 9 species was between 31-60%. Pretreatments used were not sufficient to overcome all dormancy. Further study is recommended for 7 species for which germination never exceeded 30%.

ACKNOWLEDGEMENTS

I would like to thank Dr. E. Toop for his assistance and support during the last three years. I gratefully acknowledge the financial support of the 'Friends of the University of Alberta Devonian Botanic Garden.' A special word of thanks is due to P.N.D. Seymour, R. Currah and M. Van Dyk and all the staff of the Devonian Botanic Garden who were supportive and enthusiastic. Finally, I thank my husband Nick, for his constant encouragement.

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I. INTRODUCTION

The objective of this study was to determine the germination requirements of native forbs which have potential for use in revegetation and restoration programs in grassland regions of the province of Alberta.

The grassland, which once covered vast areas of North America from Florida in the south east to Alberta in the north west, is rapidly disappearing with increasing agriculture and urbanization. In Alberta, grassland once extended to the foothills in the west and to the aspen parkland in the north. Increased public interest in environmental issues has led to an outcry to preserve natural grassland areas. Futhermore, public demands for additional natural areas have increased the need for quality restoration and reclamation programs. This interest has stimulated both government and commercial agencies to explore the possibility of restoring grassland to its native stable state.

Areas of undisturbed grassland, which still exist in Alberta, support over 150 forb species. Many have potential for use in restoration programs in the province (Currah *et. al.* 1982) but few have been considered, primarily due to the lack of information on their ecology and reproductive biology.[1] As demand for good quality native plant material has increased so has the demand for information on all

---

[1] In Manual of Plant Species Suitability For Reclamation In Alberta (Watson *et. al.* 1980) only 12 forb genera (6 of which are native to Alberta) are presented as possible choices for revegetation programs in Alberta.

aspects of the biology of grassland communities and the component species. This study is a contribution to the understanding of germination requirements of 58 species native to the grassland regions of Alberta.

Literature Review

Because several aspects of methodology in determining seed viability and germination are problematic, a brief discussion of seed testing procedures and terminology is presented below.

There are a number of procedures for testing viability of seeds. The most common method is to germinate a sample from a seed lot under conditions most suited to that species, and count seedlings. This is taken as an indication of viability (International Seed Testing Association (ISTA) 1966, MacKay 1972, Bonner 1974, Gordon and Rowe 1982). This method allows for a determination of viability and an assessment of seedling quality (MacKay 1972). There are in place standard methods for germinating seeds to test viability, and standard methods for seedling evaluation for many agricultural species (ISTA 1966, Association of Official Seeds Analysts (AOSA) 1978, Canada Department of Agriculture 1979).

There are also a number of less direct methods of testing viability and two are discussed here. Tetrazolium (TTC) salts are used as a vital stain. The salts, in a colourless solution, are reduced to a red coloured formazan,

by dehydrogenase enzymes in living tissue (Cottrell 1948, Lakon 1949). Viability can then be assessed on the basis of the distribution of the red colour in the embryo (Lakon 1949, Moore 1962, Bonner 1974). The procedure for testing seed viability with tetrazolium salts varies with plant species; the Association of Official Seeds Analysts (1970) has published methods for conducting tetrazolium (TTC) tests for many individual species of agricultural seeds.

Another viability test uses x-rays. Unfortunately, there is little information on the use of x-ray photography in viability testing although it is routinely used for seeds of trees and shrubs (Hellum, personal communication). It is not mentioned in the Rules for Testing Seed (AOSA 1978) and may be considered of limited use since it is generally used only to distinguish filled from empty seeds.

Seed 'dormancy' is the non-germination of apparently viable seeds. Various types of seed dormancy are common in temperate zone plants and, in many cases, probably ensure the survival of species during extended periods of unfavourable climatic conditions. Dormancy types are classified according to various systems which do not employ a standard set of terms. Nikolaeva's system (1977) is the most comprehensive and takes into account both factors involved in inhibiting germination and the treatments which overcome the inhibition. Her terminology is adopted for this study (TABLE 1).

TABLE 1 A review of terminology used for dormancy in seeds.

Dormancy Type (Nikolaeva 1977)	Cause	Synonyms
IMPOSED DORMANCY	-absence of suitable environmental factors such as moisture, light or temperature	Induced Dormancy (Brenchley and Warington 1930) Environmental Dormancy (Bibbey 1948) External (Hartmann and Kester 1959) Ectogenous Dormancy (Barton 1965a) Enforced Dormancy (MacKay 1972) Quiescence (Amen 1963)(Villiers 1972)
ORGANIC DORMANCY	-some innate property of the seed or its covering	Natural Dormancy (Brenchley and Warington 1930) Inherent Dormancy (Bibbey 1948) Internal Dormancy (Hartmann and Kester 1959) Endogenous Dormancy (Barton 1965a) Innate Dormancy (MacKay 1972)(Waring 1969)
Exogenous	-some property of the outer covering of the seed	Seed Coat Dormancy (Hartmann and Kester 1959) Coat-Imposed Dormancy (Waring et. al. 1973)
physical **chemical** **mechanical**	-impermeable seed coat -germination inhibitor -covering is a barrier to embryo expansion	
Endogenous	-some property of the embryo	Embryo Dormancy (Hartmann and Kester 1959) (Waring et. al. 1973)
morphological **physiological**	-underdeveloped embryo -some physiological inhibiting mechanism	
Combined	-a combination of one or more causes each of endogenous and exogenous dormancy	
Primary Dormancy	-present when seed is dispersed	Innate Dormancy (Roberts 1972)
Induced Dormancy	-maintainance of imbibed seeds in an unfavourable environment	Secondary Dormancy (Toole and Pollock 1961) (Villiers 1972)

Some authors refer to 'dormancy' as non-germination caused by some innate property of the seed (Villiers 1972), and use the term quiescence to denote seeds which do not germinate due to unsuitable environmental conditions. Nikolaeva refers to all non-germinating seeds as dormant and distinguishes between imposed dormancy which is due to the absence of suitable external conditions such as water, light and temperature, and organic dormancy, due to some innate property of the seed. Imposed dormancy is variously referred to in the literature as induced (Brenchley and Warington 1930), environmental (Bibbey 1948), external (Hartmann and Kester 1959), ectogenous (Barton 1965a) or enforced (Mackay 1972) dormancy. Organic dormancy is discussed by various authors as natural (Brenchley and Warington 1930), inherent (Bibbey 1948), internal (Hartman and Kester 1959), endogenous (Barton 1965a) or innate (Mackay 1972) dormancy. Nikolaeva recognizes 3 categories of organic dormancy; exogenous, endogenous, and combined. Exogenous dormancy is caused by properties of the outer covering of the seed and is referred to as seed-coat dormancy by Hartmann and Kester (1959) and coat-imposed dormancy by Waring *et. al.* (1973). It can be physical (impermeable seed coat), chemical (germination inhibitors in the seed or fruit coat), or mechanical (a seed coat acting as a barrier to embryo expansion). Endogenous dormancy is caused by conditions within the embryo and has been referred to as embryo dormancy (Hartmann and Kester 1959, Waring *et. al.* 1973).

Undeveloped embryos (morphological) or the presence of inhibitors and/or absence of growth promoters (physiological) may be involved in this type of dormancy. Endogenous, physiological dormancy can be further sub-divided into shallow, intermediate, or deep depending on the pregermination treatments required for complete and normal germination. Combined dormancy refers to instances in which both the outer covering and the embryo contribute to dormancy (*i.e.* a combination of both exogenous and endogenous dormancy). Primary dormancy is used in the literature to mean dormancy which exists at the time that seeds are shed (Villiers 1972), whereas secondary dormancy is induced by subjecting seeds to some unfavourable condition following imbibition (Villiers 1972, Pollock and Toole 1961). Nikolaeva refers to the latter as induced dormancy.

While it may provide plant species with a mechanism for survival, dormancy presents a problem for nurserymen who are concerned with growing large quantities of seedlings in a short period of time. Their objective is to overcome the dormant condition by the simplest and most effective method.

Several methods are available for overcoming dormancy and these vary according to dormancy type. Imposed dormancy can be overcome by placing seeds in an environment with adequate moisture and aeration, at suitable temperatures in appropriate light conditions. Organic, exogenous dormancy can be overcome either by breaking down or removing the seed

covering or by leaching out inhibitors with running water. Seed coats can be broken down by mechanical scarification or by soaking seeds in water, concentrated acid or organic solvents (Kester 1960, Krugman *et. al.* 1974). Seed coats can also be softened or broken down by placing seeds in warm moist conditions (Gordon and Rowe 1982). Methods used to overcome endogenous dormancies include, exposure of seeds to light, or to warm and/or chilling temperatures in the presence of moisture, or the application of a growth promotor such as gibberellic acid (GA_3).

The most commonly used pretreatments are cold stratification[2] or scarification. Cold stratification consists of placing seeds in a cold (usually just above freezing), moist environment for several days to several months (Bonner *et. al.* 1974). The mode of action of this treatment is not completely understood but it may result in a change in the balance between growth promotors and growth inhibitors in the embryo (Khan 1980). Koller (1972) and Lewak and Rudnicki (1977) refer to the processes which occur during stratification as 'afterripening.' Nikolaeva (1969), however, reserves this term for changes which occur in a seed during dry storage. Scarification is the breaking down of the seed or fruit coat by mechanical (abrasion), chemical (acid or organic solvents), or physical (heat, scalding) means.

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[2] referred to in this study as cold stratification or stratification. Pretreating seeds in moist warm conditions will be referred to as warm stratification.

Virtually no studies on germination and viability have been done with the grassland wildflowers of Alberta, even though there have been several studies with native wildflowers from other regions of North America (Nichols 1934, Blake 1935, Griswold 1936, Tolstead 1941, Greene and Curtis 1950, Pelton 1956, Maguire and Overland 1959, Sorensen and Holden 1974, Salac and Hesse 1975, Voight 1977, Sabo *et. al.* 1979, Hoffman *et. al.* 1980, Kasper and McWilliams 1982). These included only a few species which are also native to grassland regions of Alberta. Primarily, these studies were conducted to establish the effect of specific environmental factors on germination of seeds of different species.

Nichols (1934) studied the winter temperature requirements of 200 wildflowers from eastern North America and grouped species according to their germination response after exposure to winter temperatures. Soil was used as the germinating medium, but the author made the recommendation that tests carried out in petri dishes could be better controlled. Mo[illegible]ntrol could also be expected if seeds were germinated [illegible] laboratory conditions rather than outdoors at ambie[illegible]inter temperatures. Nichols observed that exposure to [illegible]mperature improved germination percentage and/or decreased the time for germination for many species. For some species, exposure to winter temperatures had a detrimental effect on germination, while for others there was no effect.

Blake (1935) investigated germination of grassland plants native to Kansas and Nebraska. She concluded that: (1) viability was low in seeds collected from natural populations, (2) for many seeds germination percentages were greater in the spring than in the fall immediately following harvest, (3) seeds of some grassland plants exhibit a dormancy period which can be overcome by dry cold storage, (4) stratification (moist, cold storage) was more effective than cold, dry storage for overcoming dormancy of most forbs, and (5) optimum moisture for germination was one-third to two-thirds of the saturation level of soil.

Griswold (1936) investigated the effects of alternate moistening and drying on seeds of grasses, forbs and shrubs native to Utah and concluded that some species reacted positively and others negatively to this treatment. For some species, the treatment had no apparent effect on germination. The speed at which seeds were dried also had either a beneficial or detrimental effect dependent again on the particular species being tested.

Tolstead (1941), and Greene and Curtis (1950) examined the effect of winter temperatures on germination of species collected in Nebraska and Wisconsin, respectively. They observed that exposure to winter temperatures improved germination in many wildflowers but proved detrimental to others. Greene and Curtis (1950) made some correlations between effects of stratification and taxonomic affinity. Most plants in the family Compositae responded positively to

stratification whereas those of Ranunculaceae were unaffected.

In a study of germination of 18 species of Colorado plants from high elevations, Pelton (1956) found that 7 species lacked a dormant[3] period, 4 species required scarification, 2 species required stratification and another 5 species did not respond to either treatment. He concluded that although these species all originate from an area of similar climate they do not exhibit the same dormancy mechanisms and each species must be studied individually to determine optimum germination requirements.

Maguire and Overland (1959) tested germination of many species native to Washington under various temperature and light conditions and observed the reaction of some species to stratification. They found that germination response varied within families for the most part but dormancy which could be overcome by stratification occurred in many members of the Compositae. Because results were based on a single sample of 100 seeds, one cannot be certain that observed responses were due to the treatments and not to large variation within seed lots.

Sorensen and Holden (1974) studied 23 species of wildflowers from the tallgrass grassland region of South Dakota. They identified 4 legumes which benefited from scarification based on an observed increase in percent and a decrease in time for germination. Stratification, for 1 to 3

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[3] Organic Dormancy in Nikolaeva's terminology.

months, resulted in improved germination for 8 species and treatment with gibberellic acid (GA_3) increased germination in one species. No attempt was made to explain or speculate on the mode of action by which treatments improved germination, or to correlate observed responses with the ecology of the species.

Voight (1977) also investigated germination requirements of 20 grassland forbs and observed that without pretreatment, only 3 species germinated well. Twelve germinated better following stratification and 4 benefited from scarification. Seven germinated best following a combination of scarification followed by stratification whereas 7 others showed no improvement with this treatment. Application of Rootone[4] improved germination of 5 species whereas potassium gibberellate application improved germination of 2 species. Voight did not specify which growth regulators were in Rootone nor did he discuss his reasons for choosing this treatment.

Salac & Hesse (1975) studied germination of 4 wildflower species from Nebraska and observed that germination of each species was stimulated by stratification. Specific photoperiods and alternating temperature regimes also influenced germination. They noted that germination of wild seeds was poor compared with seeds from cultivated plants of the same species. Variation in germination within and between seed lots was taken into

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[4] Alchem Products, Inc.

account by the experimental design and analysis.

Hoffman, Hogan, and Stanley (1980) undertook a study of the germination requirements of 14 plant species common to reservoir shores in South Dakota. They studied the effects of winter temperatures on dry and moistened seeds, autumn versus spring germination, and germination under light and dark conditions. One observation of considerable interest was that most species germinated best in spring rather than in the fall, suggesting that even if specific pretreatments are not required, a period of rest (afterripening) might be required for maximum germination. This, along with observations made by Blake (1935), indicate that if maximum germination is to be obtained, the most appropriate testing time is spring rather than fall immediately following harvest.

Kasper and McWilliams (1982) tested the germination of 4 forb species at different temperatures. These authors found that each species had an optimum germination temperature. Sabo *et. al.* (1979) determined the optimum germination temperature, external water potential, and light regime for 19 species of grasses and shrubs native to New Mexico. Some species germinated over a wide range of temperatures and water potentials while others had more specific requirements. In some cases, light stimulated germination.

A major problem with many of these studies is that there is no analysis of data and no discussion of

variability within or between samples (Nichols 1934, Blake 1935, Griswold 1936, Tolstead 1941, Greene and Curtis 1950, Maguire and Overland 1959, Sorensen and Holden 1974, Voight 1977). Generalizations made by these authors in the preceeding papers may be of limited value since, in many cases, tests refer to a small number of seeds and methods vary from germinating seeds in sand out of doors, to germinating seeds in petri dishes in the laboratory. Some observations and conclusions, however, were made by several authors and were considered before setting up this study. These include: (1) cold stratification is the most effective treatment to overcome dormancy displayed by temperate plants, (2) legumes often have hard (=impermeable) seed coats but scarification is effective for obtaining complete and rapid germination, (3) seeds are often dormant when shed but some of this dormancy is lost over time resulting in better germination in spring than in fall, (4) germination is variable within species for seed lots of different years and from different populations, (5) some seeds germinate within a narrow range of temperatures and moisture conditions, (6) species which propagate and grow in similar environments do not necessarily have the same germination requirements.

Objectives

There is very little information on the germination requirements of many grassland wildflowers and virtually no

information based on studies of species from northern grassland regions such as Alberta. Since both stratification and scarification are commonly used as pregermination treatments for many temperate plant species, the effectiveness of these treatments were tested on forbs native to the Alberta grassland.

This study of 58 grassland wildflower species native to Alberta[5] had the following objectives:

1. To quantify germination of seed lots collected from wild populations of each species.
2. To determine the effect of stratification on germination of seeds of all 58 species and to determine the effect of scarification on germination of seeds which appeared hard (impermeable).
3. To establish if taxonomic affinity can be used to predict germination requirements.
4. To identify species which require further study in order to develop feasible methods of mass propagation.
5. To evaluate tetrazolium staining and x-rays for their usefulness as rapid tests for predicting germination in seeds from wild populations.

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[5] species discussed here have been considered for use in revegetation projects in Alberta by Alberta Environment.

II. MATERIALS AND METHODS

Seeds[4] were collected from southern Alberta plants[7] in 1980, 1981 and 1982 by removing the ripe seeds directly from the plant or by placing the cut seed stalks in paper sacks where the seeds dropped as the stalks dried. Seeds were dried at room temperature, separated from the chaff by hand and stored dry in paper envelopes at 3-6°C. Germination and viability tests were conducted in the spring and summer of the year following collection.

Only seeds which appeared full (plump) were used in viability and germination tests. Selection was made by applying slight pressure to the seed with forceps. If there was resistance seeds were considered full. Unless otherwise noted, germination tests done in 1981 consisted of 4 replicates of 25 seeds each whereas tests in following years consisted of 4 replicates of 100 seeds each.

Two viability tests were used for seeds collected in 1981, namely tetrazolium staining and x-ray photography. Seeds were soaked in 0.1% solution of 2,3,5-triphenyl tetrazoliumchloride (TTC) solution at pH 6-7 for up to 24 hours in the dark before the embryos were examined under low magnification (AOSA 1970).

X-ray photographs were prepared by placing seeds on Kodak X-OMAT TL film plates and exposing them to 25 kv for 7 seconds. Negatives were examined on a light table. Seeds

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[4] 'Seed' refers to both true seeds and seed-like fruits such as achenes, mericarps and nutlets.
[7] Botanical names follow those used by Packer (1983).

were considered viable if the embryo was intact and not shrunken or shriveled (Hellum, personal communication).

Petri dishes with a single layer of moistened filter paper were used for testing germination. All seeds were treated with a slurry (1gm/100ml) of Arasan 75 (tetramethyl-thiuramidisulfide) to control fungal growth (Sorensen 1972). Dishes were covered and placed in germination cabinets at 22°C in the dark for 30 days. Germinated seeds were counted in the light and removed daily. Water was added as necessary*. Seeds were considered germinated if a radicle emerged through the seed coat.

Several pretreatments were used including stratification, mechanical scarification, acid scarification, soaking, and alternating temperatures. Stratification consisted of placing seeds in petri dishes and storing them moist at 1-6°C for 2 or 3 months in the dark.

Seeds were mechanically scarified by abrading the seed coats with sandpaper (GR=80 or 100) until scratches could be seen on the coat surface under low (X40) magnification. For very hard seeds, a file was used to scratch or nick the seed coat. Acid-scarified seeds were soaked in concentrated acid (either H_2SO_4 or HCl) until the coat appeared disrupted (approximately 45 minutes), seeds were then washed for several hours with running water prior to the germination test.

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*distilled water was used in 1981 and tap water in following years.

Seeds given the water-soak treatment were placed in a large amount of water at 80°C where they remained in the gradually cooling water for 24 hours at room temperature.

Seeds subjected to alternating temperatures were placed in a growth chamber in the dark for 8 hours at 5°C followed by 16 hours at 30°C for periods of 3, 4, 5, and 6 weeks.

To determine if seeds contained water-soluble germination inhibitors, 5 grams of seeds were placed in 200 ml boiling water and allowed to remain in the cooling water for 24 hours. Seeds were then removed, washed in running water for several hours and tested for germination as previously described. Soak-water was retained and used to moisten filter paper on which lettuce' seeds were placed. Germination of lettuce seeds moistened with soak-water was compared to germination of lettuce seeds moistened with tap water. Lettuce seeds were tested in the dark.

Anatomical investigations of seed coats of some species were carried out by examination of freehand or microtome sections stained with 4% Sudan IV in ethanol (Johansen 1940). Microtome sections were prepared by fixing seeds in formalin-acetic acid (FAA), dehydrating in ethanol-tertiary butyl alcohol series and embedding them in paraffin (Johansen 1940). Seed coats were also examined with a scanning electron microscope (SEM). Seeds were first frozen in liquid nitrogen for up to 30 seconds, then fractured and mounted on stubs. A coating of gold was applied with either

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'cultivar 'Grand Rapids'

a Nanotech or Edwards sputter coater. Seeds were then examined with a Cambridge S-250 SEM and photographed.

Viability and germination data were analysed using Analysis of Variance and the 'F' test.

III. RESULTS

Data from viability tests is presented in TABLE 2. Germination results are presented by botanical family in TABLES 3-12. All germination results with statistical comparisons, are included in APPENDIX 2.

There was no significant difference between results of TTC tests and x-ray tests for 31 of the 35 species tested by both methods. Results of these two tests were significantly different for the remaining 4 species (TABLE 2). Results of x-ray tests corresponded to observed germination for 19 of 34 species and TTC results were comparable to germination for 17 of the 37 tested. Viability and germination results were in closer agreement for species with high germination percentages. As germination percentages decreased so did the precision of x-ray and TTC tests.

Germination of some species was much lower than expected from viability tests. These included *Achillea millefolium*, *Astragalus drummondii*, *Besseya wyomingensis*, *Coryphantha vivipara*, *Glycyrrhiza lepidota*, *Grindelia squarrosa*, *Heuchera richardsonii*, *Musineon divaricatum*, *Opuntia polyacantha*, *Penstemon nitidus*, *Thermopsis rhombifolia*, and *Zizia aptera*. *Heterotheca villosa* germinated better than predicted by viability tests.

Germination of most legumes improved if seeds were mechanically scarified (TABLE 3). Hot water pretreatment also improved germination of most legumes but was not as effective as mechanical scarification. Stratification proved

beneficial for germination of some legumes but results were inconsistent. For collections of *Thermopsis rhombifolia* from all 3 study years, scarification resulted in an increase in germination. Tests following both stratification and scarification were done on only 2 seed lots. Higher germination percentages were observed for one seed lot but not for the other. Soaking seeds in hot water did not increase germination over untreated seeds. Both *Glycyrrhiza lepidota* and *Lupinus argenteus* germinated best if untreated. Untreated seeds of *Hedysarum alpinum* germinated as well as scarifed seeds for each of 3 collections, and the effect of stratification varied from no significant effect to a slight inhibition of germination.

Germination results varied among species of the Compositae (TABLE 4). Stratification increased germination percentages and/or decreased the time for germintion for *Achillea millefolium*, *Grindelia squarrosa*, *Haplopappus spinulosus*, *Helianthus subrhomboideus*, *Heterotheca villosa*, *Hymenoxys richardsonii*, *Madia glomerata*, *Ratibida columnifera*, and *Solidago rigida*. Results varied from year to year for *Arnica fulgens*, *Gaillardia aristata* and *Liatris punctata*. Stratified and untreated seeds of *Coreopsis tinctoria* germinated poorly whereas seeds of *Senecio canus* germinated well regardless of treatment.

Germination of *Anemone cylindrica* and *Anemone multifida* was generally unaffected by stratification (TABLE 5, APPENDIX 2) *Anemone patens* germinated poorly regardless of

treatment although untreated seeds germinated significantly better than stratified seeds. For all three species, germination did not commence for at least a week after being placed in germinators.

Germination percentages were high for both *Geum aleppicum* and *Geum triflorum*. Stratifying seeds sometimes decreased the germination time (TABLE 6).

Stratification increased germination of *Allium cernuum* (TABLE 7). This treatment in combination with scarification was most effective for germination of *Allium textile*. *Smilacina stellata* germinated best if stratified, whereas *Yucca glauca* seeds germinated as well if either stratified or left untreated.

Germination results of Cactaceae species varied from collection to collection (TABLE 8). *Coryphantha vivipara* seeds collected in 1980 germinated well but seeds collected in 1982 germinated poorly. In either case no difference was observed between untreated and stratified seeds. The 1981 seed lot germinated best if stratified. The time required for germination was inconsistent from collection to collection and among treatments. In most cases seeds swelled (imbibed water) even when germination was poor. *Opuntia polyacantha* seeds collected in 1980, germinated best if either stratified or scarified but germination in both cases was extemely poor. Soaking *Opuntia* seeds in hot water had no effect on their germination. The 1981 seed lot germinated poorly regardless of treatment. The best germination for

this species was observed in seeds collected in 1982 with highest percentages obtained when seeds were stratified for 2 or 3 months. *Opuntia polyacantha* seeds which were subjected to alternating warm and cold temperatures germinated significantly better than untreated seeds (TABLE 9). No difference was noted between germination percentages of seed lots which were subjected to 3, 4, 5, or 6 weeks of alternating temperatures.

Germination results for Umbelliferae species are presented in TABLE 10. *Zizia aptera* germinated poorly in all tests but 2 year old seeds germinated with highest percentages following 2 or 3 months of stratification. *Musineon divaricatum* seeds also germinated poorly, however, 2 year old seeds germinated best if stratified for 3 months.

Penstemon nitidus seeds collected in 1980 germinated poorly regardless of treatment (TABLE 11). Seeds collected in 1981 and 1982 germinated best if stratified; for the 1982 collection, 3 months of stratification was better than 2. Maximum germination of 2 year old seeds was observed following 3 months stratification. Seed lots of *Penstemon procerus* collected in 1981 and 1982 germinmated best if stratified although this treatment did not increase germination of seeds collected in 1980. Untreated seeds of *Besseya wyomingensis* germinated poorly. The 1980 collection also germinated poorly if stratified. Seeds collected in 1981 germinated significantly better if stratified but germination percentages were still extremely low.

Scarification had no apparent effect on germination. Seeds of the 1982 seed lot germinated best if stratified, with 3 months being more effective than 2. Soaking seeds in hot water resulted in no increase in germination. Two year old seeds germinated best if stratified for 2 or 3 months.

Germination results for the remaining species are presented in TABLE 12. Germination of *Arenaria congesta* var. *lithophila*, *Cleome serrulata*, and *Viola adunca* increased if seeds were stratified, although germination of *Cleome* was low regardless of treatment. Seeds of *Arenaria congesta* var. *lithophila* which did not germinate were hard (impermeable), showing no apparent imbibition. Untreated seeds of *Heuchera richardsonii* and *Plantago purshii* germinated significantly better than stratifed seeds. *Collomia linearis* and *Sisyrinchium montanum* failed to germinate regardless of treatment. *Dodecatheon conjugens* germinated best if stratified. Germination percentages never exceeded 31%. Stratified seeds of *Eriogonum flavum* germinated better and faster than untreated seeds for the 1981 collection. For seeds collected in 1982, no significant differences in germination were observed between stratified and untreated seed lots.

Seeds of *Lithospermum ruderale* germinated best if stratified. For all 3 collections, seeds failed to germinate if untreated. Removing seeds from the fruit covering resulted in an increase in germination but germination was still extremely poor.

In the 1980 collection, maximum germination of *Monarda fistulosa* var. *menthifolia* was recorded if seeds were stratified, but in 1982 there was no significant difference between untreated seeds and stratified seeds. *Oenothera biennis* seeds consistently germinated best if stratifed.

Soaking seeds of *Besseya wyomingensis*, *Lithospermum ruderale*, *Penstemon nitidus*, *Opuntia polyacantha* and *Zizia aptera* in hot water had no effect on their germination. In each case there was no difference in germination performance between soaked and untreated seeds. When the soak-water from these seeds was used to moisten lettuce seeds, no significant effect was observed on the germination of the lettuce (TABLE 13).

Anatomical features of seed coats vary among the five species studied (*Besseya wyomingensis*, *Lithospermum ruderale*, *Penstemon nitidus*, *Opuntia polyacantha*, and *Zizia aptera*).

The outer epidermis of *Opuntia polyacantha* is a multiseriate layer of thick-walled, sclerified cells (FIGURE 1A, FIGURE 2A). The inner epidermis is composed of 2 layers; the outer is pigmented. A waxy layer is present between the inner epidermis and the endosperm.

The seed coat of *Besseya wyomingensis* appears waxy on the surface and consists of a single, apparently non-cellular layer (FIGURE 1C, FIGURE 2B,C). This cuticular layer is unevenly deposited on the surface of the seeds (FIGURE 2E). The endosperm is to the immediate inside of the

cuticle.

The seed coat of *Penstemon nitidus* is composed of 2 layers: the outer, which is papery and a hard inner layer. A section of the seed coat shows that the outer layer is composed of thick-walled cells. Cells of the inner, uniseriate layer have thickened end walls next to the endosperm (FIGURE 1B, FIGURE 2D).

The fruit wall of *Zizia aptera* is waxy on the surface, and is punctuated by stomata. The pericarp consists of numerous layers of parenchymatous cells interrupted by vascular bundles and oil ducts (FIGURE 2F, FIGURE 3A). The seed coat is made up of several layers which are somewhat compressed (FIGURE 3B). The pericarp of *Lithospermum ruderale* is very hard and thin sections were impossible to obtain. The pericarp is composed of a thick outer layer of tighly compact cells covered by a cuticle (FIGURE 2G). The innermost layer next to the embryo is thin and papery.

TABLE 2 A comparison of results of x-ray photography, tetrazolium staining and germination tests. For each collection, means followed by a different letter are significantly different for $P<0.05$.

Collection	X-ray Mean[1] ± SD	TTC Stain Mean[1] ± SD	Maximum Observed Germination Mean[1] ± SD
Achillea millefolium	93.00± 2.16 a	99.00± 0.82 b	63.70± 4.11 c
Allium textile	97.25± 0.50 a	99.25± 0.96 b	81.75± 0.50 c
Anemone cylindrica	92.00± 2.16 a	94.00± 3.27 a	74.75±11.10 b
Anemone multifida	94.50± 2.65 a	94.50± 2.65 a	86.00± 8.29 a
Antennaria nitida	98.00± 2.45 a	97.00± 0.82 a	87.50± 3.11 b
Arnica fulgens	94.75± 2.99 a	96.25± 3.50 a	91.00±10.68 a
Astragalus bisulcatus	95.75± 2.87 a	94.25± 2.87 a	93.25± 4.99 a
Astragalus drummondii		88.50± 2.65 a	55.25±10.78 b
Astragalus gilviflorus[1]	99.50± 0.71 a	96.50± 2.12 a	92.00± 5.66 a
Astragalus pectinatus	96.00± 2.45 a	99.25± 0.96 a	94.75± 4.35 a
Astragalus striatus	99.75± 0.50 a	99.75± 0.50 a	99.25± 1.50 a
Besseya wyomingensis		78.00± 7.02 a	2.25± 0.96 b
Coryphantha vivipara		99.50± 0.58 a	24.25± 7.93 b
Eriogonum flavum[1]	89.00± 8.49 a	95.50± 2.12 a	97.50± 0.71 a
Gaillardia aristata[1]	98.67± 0.58 a	97.25± 1.71 a	92.00± 1.41 b
Gaillardia aristata[4]	74.00± 2.45 a	79.00± 4.97 a	57.50±14.50 b
Geum aleppicum	100.00± 0.00 a	99.00± 1.15 a	100.00± 0.00 a
Geum triflorum	99.00± 0.82 a	97.50± 1.00 a	98.75± 1.50 a

continued

TABLE 2 A comparison of results of x-ray photography, tetrazolium staining and germination tests. For each collection, means followed by a different letter are significantly different for $P<0.05$.

Collection	X-ray Mean[1] ± SD	TTC Stain Mean[1] ± SD	Maximum Observed Germination Mean[1] ± SD
Glycyrrhiza lepidota	81.25± 2.22 a	86.50± 2.08 a	31.00±12.99 b
Grindelia squarrosa	97.50± 1.91 a	98.50± 0.58 a	64.25± 6.50 b
Haplopappus spinulosus	82.50± 9.26 a	94.25± 1.89 b	95.00± 2.94 b
Hedysarum alpinum	99.00± 0.00 a	99.25± 5.25 a	98.50± 1.29 a
Heterotheca villosa	92.00± 5.23 a	91.50± 1.29 a	98.50± 3.00 b
Heuchera richardsonii		97.50± 1.73 a	57.00± 2.94 b
Hymenoxys richardsonii	95.75± 0.50 a	88.75± 9.36 a	95.25± 6.60 a
Liatris punctata	95.75± 2.50 a	99.00± 1.15 a	98.00± 4.00 a
Linum lewisii	98.75± 1.50 a	99.00± 0.82 a	81.25± 5.56 b
Monarda fistulosa var. *menthifolia*	94.75± 3.40 a	93.25± 1.71 a	83.00±10.13 a
Musineon divaricatum	99.50± 0.58 a	96.75± 1.71 b	1.25± 1.26 c
Oenothera biennis	86.75± 1.26 a	87.00± 1.83 a	79.50± 5.07 b
Opuntia polyacantha	98.00± 1.63 a	97.75± 1.71 a	2.00± 2.45 b
Oxytropis monticola	99.25± 0.50 a	99.00± 1.41 a	98.00± 1.83 a
Oxytropis sericea var. *spicata*	99.75± 0.50 a	98.00± 0.00 a	92.75± 4.27 b
Penstemon nitidus	94.50± 3.42 a	90.25± 1.71 a	14.50± 5.51 b
Penstemon procerus	97.75± 2.06 a	92.75± 1.71 a	62.75± 8.77 b
Petalostemon purpureum	98.00± 1.15 a	98.00± 0.82 a	96.25± 0.96 a

continued

TABLE 2 . A comparison of results of x-ray photography, tetrazolium staining and germination tests. For each collection, means followed by a different letter are significantly different for $P<0.05$.

Collection	X-ray Mean[1] ± SD	TTC Stain Mean[1] ± SD	Maximum Observed Germination Mean[1] ± SD
Solidago rigida	79.25± 4.35 a	72.50± 3.32 a	71.25± 5.32 a
Thermopsis rhombifolia	94.75± 3.30 a	94.50± 4.65 a	53.30±25.90 b
Zizia aptera	96.50± 0.58 a	94.75± 0.50 a	2.00± 1.83 b

[1]means are based on four replicates of 100 seeds each
[2]means based on two replicates of 100 seeds each
[3]seeds collected at Elkwater Lake
[4]seeds collected at Milk River Ridge Reservoir

TABLE 3 Germination percentages and time required for germination for seed collections of species in the Leguminosae. Germination percentages are given as averages for replicates. For the number of seeds and replicates used and for the statistical analysis refer to APPENDIX 2.

	Collection					
	1980		1981		1982	
	Germ. (%)	Time[1] (Days)	Germ. (%)	Time[1] (Days)	Germ. (%)	Time[1] (Days)
Astragalus bisulcatus						
untreated	4	28	23	30		
stratified			26	28		
scarified	76	29	93	23		
scarified/stratified			90	8		
soaked	39	30				
Astragalus crassicarpus						
untreated			11	28	11	23
stratified			7	30	14	13
scarified			97	14	100	30
scarified/stratified					80	0[2]
Astragalus drummondii						
untreated			5	30		
stratified			8	25		
scarified			55	13		
scarified/stratified			40	23		
Astragalus gilviflorus						
untreated			33	28		
scarified			92	30		
Astragalus pectinatus						
untreated	29	30	21	30	0	--
stratified			7	29	0	--
scarified	90	28	95	14	1	2
scarified/stratified			89	5	0	--
soaked	75	29				
Astragalus striatus						
untreated	11	29	9	29	20	29
stratified			19	30	3	17
scarified	97	24	99	5	80	5
scarified/stratified			85	28	78	4
soaked	47	29				
Glycyrrhiza lepidota						
untreated			31	30		
stratified			1	26		
scarified			12	29		
scarified/stratified			14	19		

[1]days for all germinating seeds to germinate
[2]all seeds which germinated did so during pretreatment

continued

TABLE 3 Germination percentages and time required for germination for seed collections of species in the Leguminosae. Germination percentages are given as averages for replicates. For the number of seeds and replicates used and for the statistical analysis refer to APPENDIX 2.

	Collection 1980		1981		1982	
	Germ. (%)	Time[1] (Days)	Germ. (%)	Time[1] (Days)	Germ. (%)	Time[1] (Days)
Hedysarum alpinum						
untreated	92	30	99	30	97	29
stratified			66	30	87	23
scarified	100	10	96	15	88	10
scarified/stratified			93	6	72	0[2]
soaked	78	27				
Lupinus argenteus						
untreated	54	27				
scarified	34	6				
soaked	10	13				
Oxtropis monticola						
untreated	19	28	4	16	12	19
stratified			43	27	7	24
scarified	82	28	98	17	98	18
scarified/stratified			91	29	91	1
soaked	40	30				
Oxtropis sericea var. *spicata*						
untreated			14	29	17	28
stratified			33	27	12	27
scarified			93	22	94	8
scarified/stratified			84	23	85	1
Petalostemon candidum						
untreated	72	26				
scarified	96	8				
soaked	74	17				
Petalostemon purpureum						
untreated			50	30		
stratified			49	28		
scarified			96	10		
scarified/stratified			57	14		
Thermopsis rhombifolia						
untreated	9	30	5	29	4	24
stratified			14	7	11	30
scarified	77	30	45	30	57	30
scarified/stratified			53	19	67	6
soaked	13	29				

[1] days for all germinating seeds to germinate
[2] all seeds germinating did so during pretreatment

TABLE 4 Germination percentages and time required for germination for seed collections of species in the Compositae. Germination percentages are given as averages for replicates. For the number of seeds and replicates used and for the statistical analysis refer to APPENDIX 2.

	Collection 1980		1981		1982	
	Germ. (%)	Time[1] (Days)	Germ. (%)	Time[1] (Days)	Germ. (%)	Time[1] (Days)
Achillea millefolium						
untreated	33	29	22	20	40	26
stratified	77	12	64	16	77	29
Antennaria nitida						
untreated	10	27	16	30	100	7
stratified			88	22	92	30
Arnica fulgens						
untreated			79	27	64	28
stratified			91	25	98	10
Coreopsis tinctoria						
untreated	1	2				
stratified	0	--				
Gaillardia aristata[2]						
untreated	78	15	81	30		
stratified	68	10	92	24		
Gaillardia aristata[3]						
untreated			58	30	46	29
stratified			40	23	64	7
Grindelia squarrosa						
untreated	6	26	11	30	5	29
stratified	3	5	64	15	30	30
Haplopappus spinulosus						
untreated			86	15		
stratified			95	8		
Helianthus subrhomboideus						
untreated			0	--		
stratified			54	23		
Heterotheca villosa						
untreated	95	16	88	29	96	16
stratified	100	8	99	6	92	7
Hymenoxys richardsonii						
untreated	90	10	79	7	67	21
stratified			95	6	86	9
Liatris punctata						
untreated	99	7	96	8	77	9
stratified	99	3	98	18	99	6

[1]days for all germinating seeds to germinate
[2]collected at Elkwater Lake
[3]collected at Milk River Ridge Reservoir

continued

TABLE 4 Germination percentages and time required for germination for seed collections of species in the Compositae. Germination percentages are given as averages for replicates. For the number of seeds and replicates used and for the statistical analysis refer to APPENDIX 2.

	Collection					
	1980		1981		1982	
	Germ. (%)	Time' (Days)	Germ. (%)	Time' (Days)	Germ. (%)	Time' (Days)
Madia glomerata						
untreated	37	27				
stratified	68	4				
Ratibida columnifera						
untreated	17	20				
stratified	38	3				
Senecio canus						
untreated			83	30		
stratified			72	30		
Solidago rigida						
untreated	83	30	34	29		
stratified	88	9	71	14		

'days for all germinating seeds to germinate

TABLE 5 Germination percentages and time required for germination for seed collections of species in the Ranunculaceae. Germination percentages are given as averages for replicates. For the number of seeds and replicates and for the statistical analysis refer to APPENDIX 2.

	Collection 1980		1981		1982	
	Germ. (%)	Time' (Days)	Germ. (%)	Time' (Days)	Germ. (%)	Time' (Days)
Anemone cylindrica						
untreated	74	30	72	30		
stratified	70	28	75	30		
Anemone multifida						
untreated	11	30	85	30	83	29
stratified	2	27	86	30	82	29
Anemone patens						
untreated	10	30				
stratified	1	29				

'days for all germinating seeds to germinate

TABLE 6 Germination percentages and time required for germination for seed collections of species in the Rosaceae. Germination percentages are given as averages for replicates. For the number of seeds and replicates and for the statistical analysis refer to APPENDIX 2.

	Collection 1980		1981		1982	
	Germ. (%)	Time' (Days)	Germ. (%)	Time' (Days)	Germ. (%)	Time' (Days)
Geum aleppicum						
untreated	98	6	100	12	100	17
stratified	100	4	100	6	100	16
Geum triflorum						
untreated	95	9	97	28	97	29
stratified	96	8	99	8	99	19

'days for all germinating seeds to germinate

TABLE 7 Germination percentages and time required for germination for seed collections of species in the Liliaceae. Germination percentages are given as averages for replicates. For the number of seeds and replicates and for the statistical analysis refer to APPENDIX 2.

	Collection					
	1980		1981		1982	
	Germ. (%)	Time' (Days)	Germ. (%)	Time' (Days)	Germ. (%)	Time' (Days)
Allium cernuum						
untreated	9	28				
stratified	26	30				
scarified	88	15				
Allium textile						
untreated			7	30	4	30
stratified			28	30	19	27
scarified			63	11	9	29
scarified/stratified			82	22	44	7
Smilacina stellata						
untreated	86	30	60	30	0	--
stratified			82	30	12	30
Yucca glauca						
untreated			84	30		
stratified			89	28		

'days for all germinating seeds to germinate

TABLE 8 Germination percentages and time required for germination for seed collections of species in the Cactaceae. Germination percentages are given as averages for replicates. For the number of seeds and replicates and for the statistical analysis refer to APPENDIX 2.

	Collection 1980		1981		1982	
	Germ. (%)	Time' (Days)	Germ. (%)	Time' (Days)	Germ. (%)	Time' (Days)
Coryphantha vivipara						
untreated	72	26	4	21	1	13
stratified	77	12	24	30	1	18
Opuntia polyacantha						
untreated	0	--	0	--	2	21
stratified (2mo)	6	30	1	12	38	29
stratified (3mo)					36	24
scarified	1	25	1	29		
soaked	0	--			0	--
acid(H_2SO_4)			0	--		
acid(HCl)			0	--		
Opuntia polyacantha(tested 1983)						
untreated			0	12		
stratified (2mo)			7	27		
stratified (3mo)			7	16		

'days for all germinating seeds to germinate

TABLE 9 Effect of alternating temperature treatment on the germination of *Opuntia polyacantha* seeds collected in 1982.

Treatment[1]	Average Germination (%)[2]		Germination Time (Days)
Untreated	4.25	a	30
3 weeks	15.75	b	30
4 weeks	16.00	b	29
5 weeks	13.50	b	30
6 weeks	12.00	b	30

[1] temperature alternated between 5°C for 8 hours and 30°C for 16 hrs.
[2] percentages followed by the same letter are not significantly different at $p<0.05$.

TABLE 10 Germination percentages and time required for germination for seed collections of species in the Umbelliferae. Germination percentages are given as averages for replicates. For the number of seeds and replicates and for the statistical analysis refer to APPENDIX 2.

	Collection 1980 Germ. (%)	1980 Time' (Days)	1981 Germ. (%)	1981 Time' (Days)	1982 Germ. (%)	1982 Time' (Days)
Musineon divaricatum						
untreated	0	--	1	16		
stratified	7	30	1	12		
Musineon divaricatum (tested 1983)						
untreated			0	3		
stratified (2mo)			2	21		
stratified (3mo)			5	8		
Zizia aptera						
untreated	2	2	0	--	0	-
stratified (2mo)	12	16	2	12	0	1
stratified (3mo)					1	10
soaked					0	--
Zizia aptera (tested 1983)						
untreated			0	--		
stratified (2mo)			10	14		
stratified (3mo)			11	15		

'days for all germinating seeds to germinate

TABLE 11 Germination percentages and time required for germination for seed collections of species in the Scrophulariaceae. Germination percentages are given as averages for replicates. For the number of seeds and replicates and for the statistical analysis refer to APPENDIX 2.

	Collection 1980 Germ. (%)	1980 Time[1] (Days)	1981 Germ. (%)	1981 Time[1] (Days)	1982 Germ. (%)	1982 Time[1] (Days)
Besseya wyomingensis						
untreated	0	--	0	30	2	26
stratified (2mo)	2	7	2	9	64	30
stratified (3mo)					72	13
scarified			1	21		
soaked					0	--
Besseya wyomingensis (tested 1983)						
untreated			2	28		
stratified (2mo)			79	24		
stratified (3mo)			82	21		
Penstemon nitidus						
untreated	7	27	1	29	2	27
stratified (2mo)	0	--	15	6	19	10
stratified (3mo)					56	6
soaked					1	0[2]
Penstemon nitidus (tested 1983)						
untreated			1	30		
stratified (2mo)			21	8		
stratified (3mo)			45	21		
Penstemon procerus						
untreated	32	29	6	28	7	28
stratified	45	11	63	26	15	14

[1]days for all germinating seeds to germinate
[2]all seeds which germinated did so during pretreatment

TABLE 12 Germination percentages and time required for germination for seed collections of species representing several plant families. Germination percentages are given as averages for replicates. For the number of seeds and replicates and for the statistical analysis refer to APPENDIX 2.

	Collection 1980		1981		1982	
	Germ. (%)	Time' (Days)	Germ. (%)	Time' (Days)	Germ. (%)	Time' (Days)
Arenaria congesta var. *lithophila*						
untreated	55	27				
stratified	71	14				
Cleome serrulata						
untreated	3	22				
stratified	20	1				
Collomia linearis						
untreated	0	--				
stratified	0	--				
Dodecatheon conjugens						
untreated	0	--	1	27	0	--
stratified	5	23	31	29	16	14
scarified			2	29		
Eriogonum flavum						
untreated			88	28	31	30
stratified			98	13	47	28
Heuchera richardsonii						
untreated	33	29	57	30	90	29
stratified	3	14	3	14	25	22
Linum lewisii						
untreated	84	26	71	30	89	30
stratified	96	2	81	15	92	6
Lithospermum ruderale						
untreated	0	--	0	--	0	--
stratified (2mo)	31	22	2	11	4	1
stratified (3mo)					0	0
embryo removed	14	28				
soaked	0	--			0	--
Monarda fistulosa var. *menthifolia*						
untreated	78	9	83	22		
stratified	95	6	78	22		
Oenothera biennis						
untreated	1	5	18	26	43	30
stratified	30	5	80	12	92	14
Plantago patagonica var. *patagonica*						
untreated	58	13				
stratified	26	28				
Sisyrinchium montanum						
untreated	0	--				
stratified	0	--				

'days for all germinating seeds to germinate

continued

TABLE 12 Germination percentages and time required for germination for seed collections of species representing several plant families. Germination percentages are given as averages for replicates. For the number of seeds and replicates and for the statistical analysis refer to APPENDIX 2.

	Collection					
	1980		1981		1982	
	Germ. (%)	Time' (Days)	Germ. (%)	Time' (Days)	Germ. (%)	Time' (Days)
Viola adunca						
untreated	2	30				
stratified	74	14				

'days for all germinating seeds to germinate

TABLE 13 Germination of lettuce seeds treated with rinse water from soaked seeds of native forbs.

Treatment	Lettuce Germination (%)[1]	
Tap Water	96.25	a
Rinse Water from *Besseya wyomingensis*	94.5	a
Rinse water from *Lithospermum ruderale*	83.25	a
Rinse Water from *Opuntia polyacantha*	93.5	a
Rinse Water from *Penstemon nitidus*	94.25	a
Rinse Water from *Zizia aptera*	86.25	a

[1]percentages followed by the same letter are not significantly different at $P<0.05$.

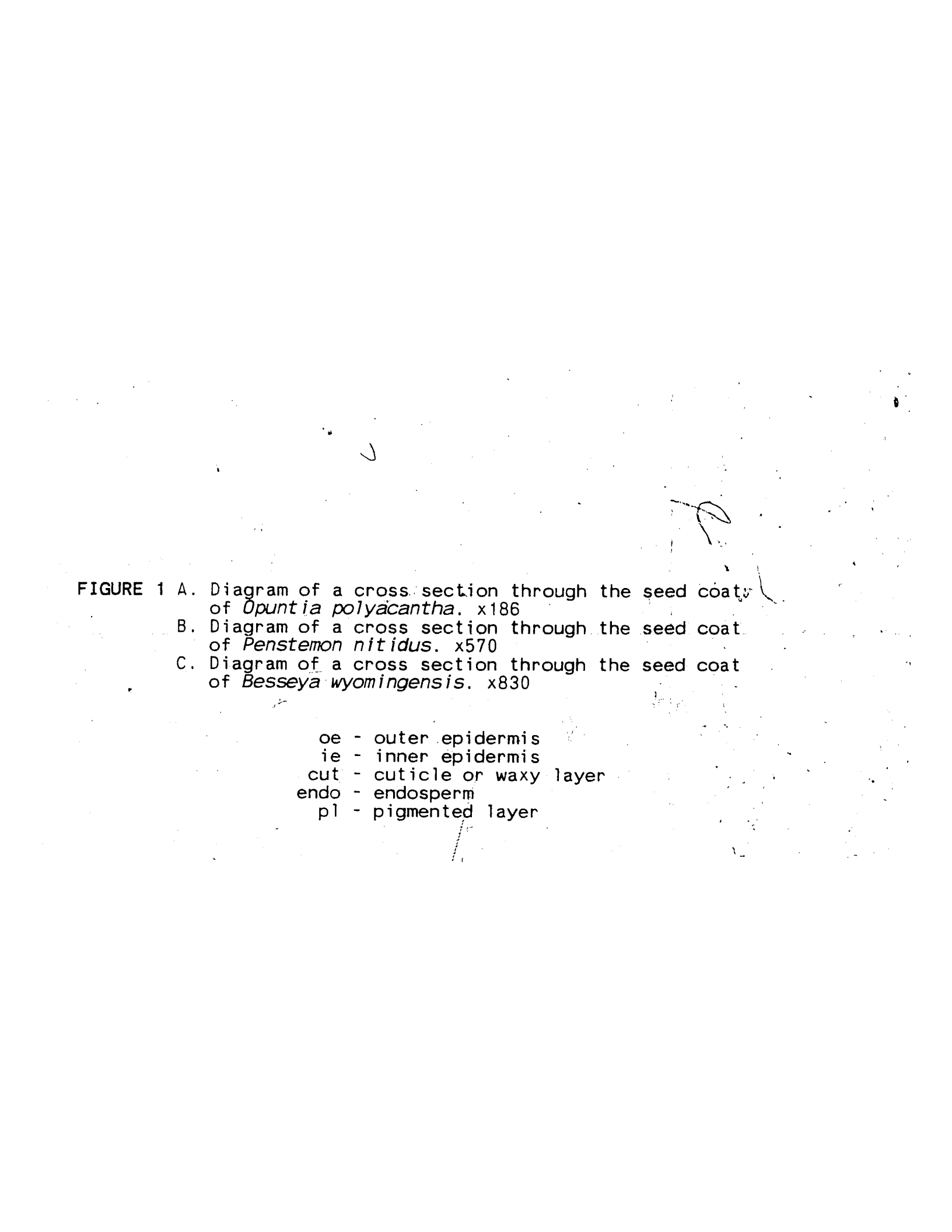
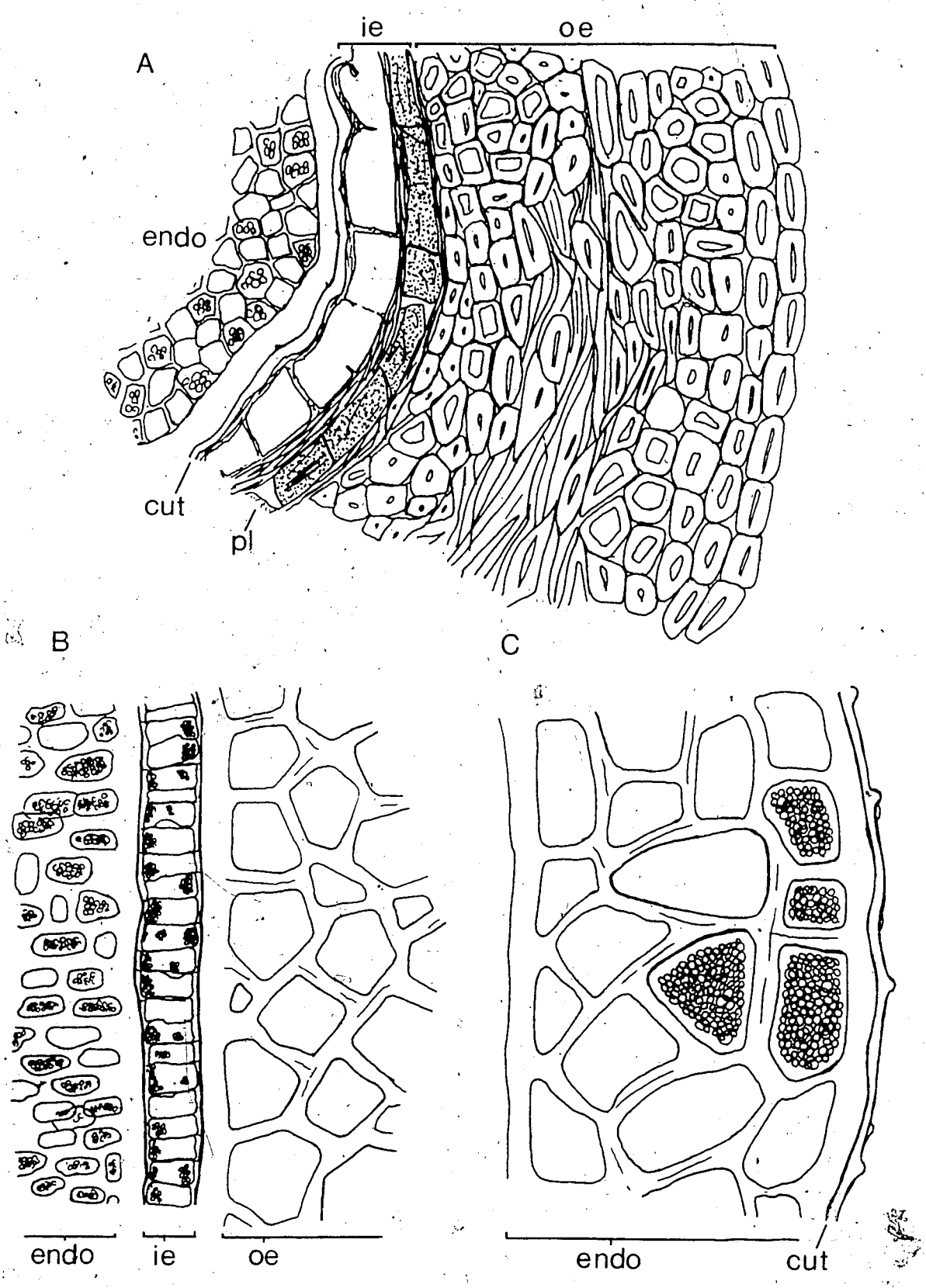


FIGURE 1 A. Diagram of a cross section through the seed coat of *Opuntia polyacantha*. x186
B. Diagram of a cross section through the seed coat of *Penstemon nitidus*. x570
C. Diagram of a cross section through the seed coat of *Besseya wyomingensis*. x830

oe - outer epidermis
ie - inner epidermis
cut - cuticle or waxy layer
endo - endosperm
pl - pigmented layer


A
ie
oe
endo
cut
pl
B
endo
ie
oe
C
endo
cut

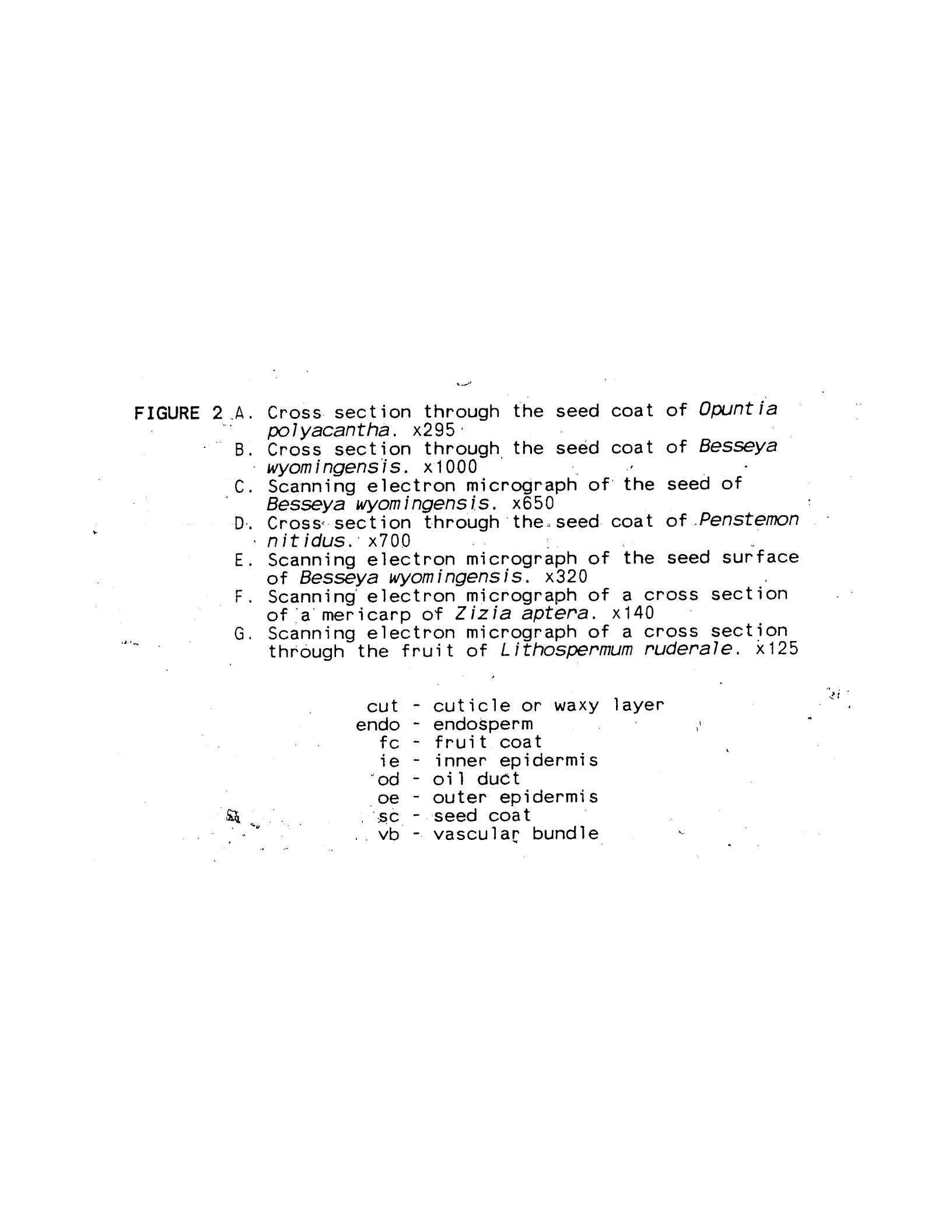


FIGURE 2 A. Cross section through the seed coat of *Opuntia polyacantha*. x295
B. Cross section through the seed coat of *Besseya wyomingensis*. x1000
C. Scanning electron micrograph of the seed of *Besseya wyomingensis*. x650
D. Cross section through the seed coat of *Penstemon nitidus*. x700
E. Scanning electron micrograph of the seed surface of *Besseya wyomingensis*. x320
F. Scanning electron micrograph of a cross section of a mericarp of *Zizia aptera*. x140
G. Scanning electron micrograph of a cross section through the fruit of *Lithospermum ruderale*. x125

cut - cuticle or waxy layer
endo - endosperm
fc - fruit coat
ie - inner epidermis
od - oil duct
oe - outer epidermis
sc - seed coat
vb - vascular bundle

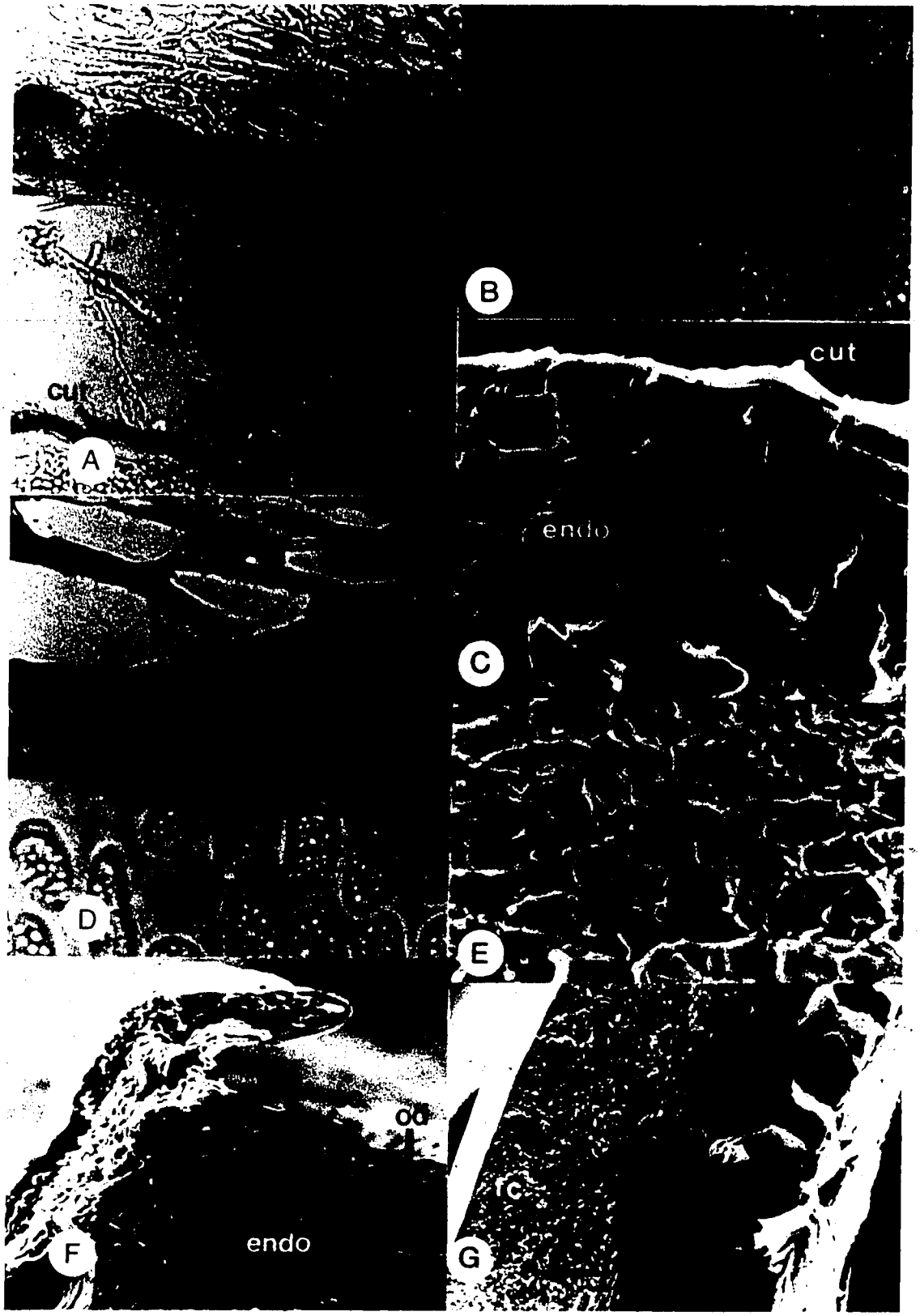
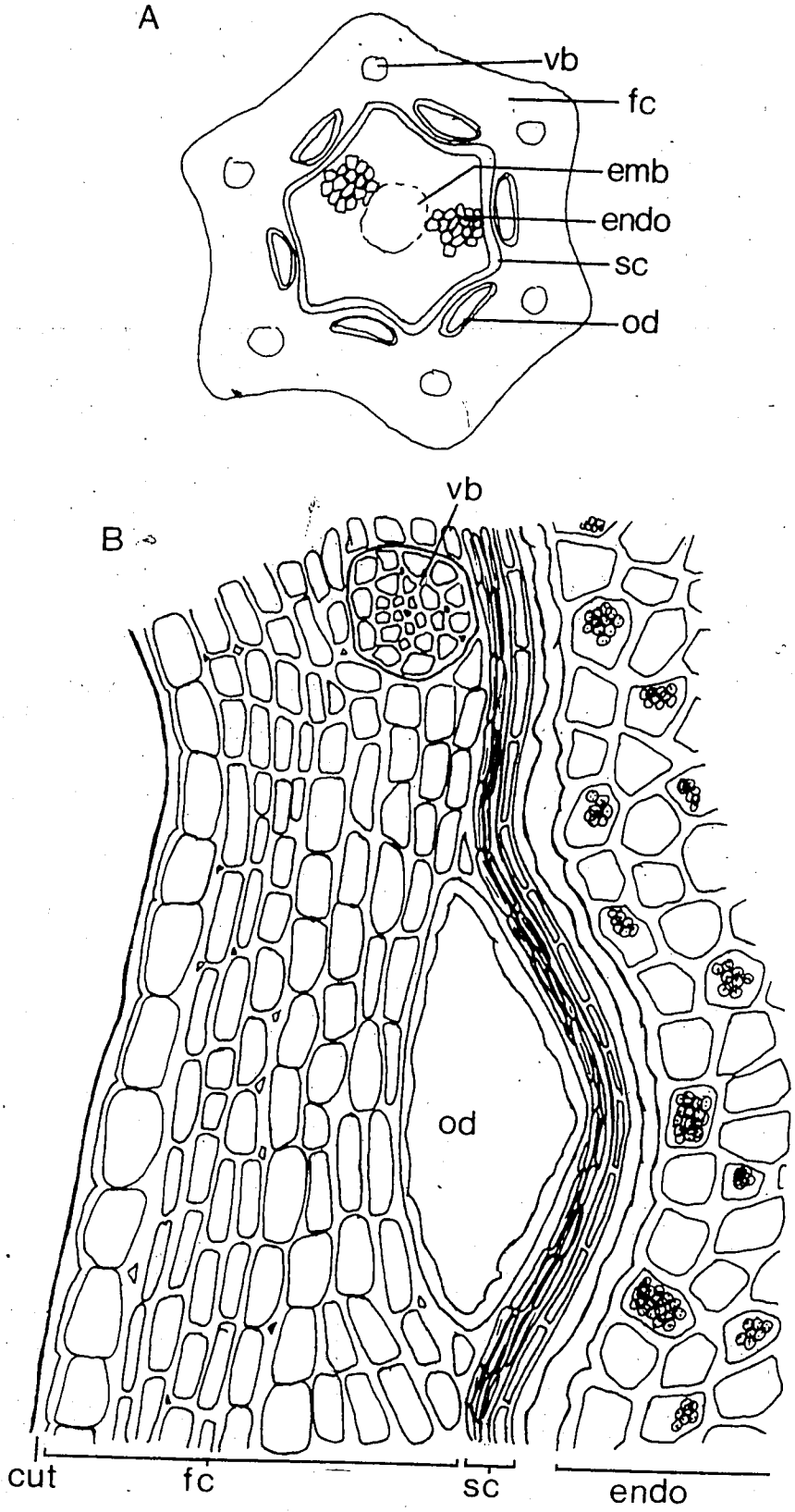

cut
A
B
cut
endo
C
D
E
od
endo
F
G

FIGURE 3 A. Diagram of a cross section of a mericarp of *Zizia aptera*. x20
B. Diagram of a cross section through the fruit and seed coats of *Zizia aptera*. x750

cut - cuticle
endo - endosperm
emb - embryo
fc - fruit coat
od - oil duct
sc - seed coat
vb - vascular bundle


A
vb
fc
emb
endo
sc
od
B
vb
od
cut
fc
sc
endo

IV. DISCUSSION

Several problems were encountered with the interpretation of staining patterns in the TTC tests with seeds used in this study. The 'Tetrazolium Testing Handbook' (AOSA 1970) states that dicotyledon seeds 'completely or mostly unstained' have to be considered non-germinable. If this were true, many of the seed lots tested would have had very low viabilities. This was not confirmed by germination test results. Moore (1973), more rationally, suggests that "colour intensity and staining patterns are of major importance in evaluation, ... correct evaluation requires a commonsense appraisal of presence, location and nature of normal, weak, dead and fractured tissues. Condition and colour of tissue must sometimes be used jointly in evaluation." Moore's criteria were more applicable for most species tested. For some species, only a few seeds in any lot stained. Unstained seeds were considered viable if the embryos were firm rather than shrivelled and white rather than grey or yellow (*e.g. Anemone cylindrica, A. multifida,* and *Linum lewisii*). The viability of these seeds was confirmed by high germination percentages.

One of the reported advantages of using tetrazolium stain as a viability test is that dormant seeds can be tested without prior pretreatment (Hartmann and Kester 1959). Physical, exogenous dormancy, however, does limit the use of vital stains since the stain must enter the seed. Seeds with impermeable coats must be prepared by scarring or

removing the coat prior to staining. It is therefore important to be aware if this type of dormancy is typical of seeds to be tested. Justice (1972) notes that tetrazolium stain is not accepted as a universal test for viability because of (1) the difficulty in staining seeds of some species, (2) poor agreement of results with germination results of seed lots of low viability, and (3) no uniform standard of interpretation of results.

To determine if TTC tests can be used effectively for a given species, it would be useful to compare a large number of TTC test results with germination test results carried out under optimum germinating conditions, following appropriate pretreatments.

Another rapid test of viability is the embryo excision method (Heit 1955, Bonner 1974). The embryo is removed from the seed and placed on a suitable moist medium such as a blotter or filter paper. After 2 to 15 days seeds are considered viable if the embryos have started to grow, turned green, remained firm and white, or have enlarged. Non-viable seeds are those for which the embryos have moulded, deteriorated, or discoloured. Presumably, this method is limited only by the ability to remove the embryo from the seed. This test is less rapid than TTC but may be used to determine if seed lots are dormant.

Dead tissues and small dead areas in embryos are not always detectable by the use of x-rays, but embryos will often shrivel when dead and this can be detected. Viability

counts by this method might be slightly greater than by germination counts. X-ray photographs are often used because (1) they are rapid, (2) little seed preparation is necessary, and (3) certain types of damage such as cracked and shrivelled embryos or insect damage can be detected. A problem was encountered with the application of this method to very small seeds such as *Heuchera richardsonii* and *Coryphantha vivipara*. The resolution was such that no detail of the embryo could be seen on the negatives. X-ray results give no information as to the presence or absence of dormancy.

Since viability was the same for 31 of 35 species tested by both methods, both TTC and x-ray photography can be considered equally efficient for measuring viability. It is interesting to note that there was a greater correlation between germination test results and those of rapid tests (x-ray and tetrazolium) for species which had high observed germination percentages. For many seed lots germination was lower than predicted by viability test results. There are 2 explanations for this. The first is that a few seeds in any given lot were weaker than others and could not germinate within the environmental conditions given, and secondly, pretreatments applied were not of sufficient duration to overcome dormancy in all seeds. Either of these could explain the discrepancies in results for species where germination percentages were only slightly less than viability results, such as *Antennaria nitida*, *Gaillardia*

aristata (collected at Elkwater Lake), *Linum lewisii*, *Monarda fistulosa* var. *menthifolia*, *Oenothera biennis*, and *Oxytropis sericea* var. *spicata*. For species where there was a large difference between results of germination and rapid viability tests, it could have been due to dormancy which was not overcome by the pretreatments given (*e.g.* inappropriate pretreatment) or to an imposed dormany due to unsuitable environmental conditions. This could be the explanation for results obtained with *Besseya wyomingensis*, *Coryphantha vivipara*, *Glycyrrhiza lepidota*, *Grindelia squarrosa*, *Musineon divaricatum*, *Opuntia polyacantha*, and *Zizia aptera*.

The most suitable test for viability depends on a number of factors, including, accuracy required, species being tested, and the time limit involved. A problem with the use of rapid viability tests is that even if seeds are found to be viable, germination may only occur under very specific environmental conditions, so that viability is not necessarily a measure of germinability under field or greenhouse conditions. The most accurate determination of germinability is achieved if a sample of a given seed lot is germinated under suitable environmental conditions following appropriate pretreatments. In undertaking this test it is assumed that germination requirements are known and the type of dormancy for a species is documented.

A count of full seeds can be obtained rapidly from x-rays. Certain types of damage can be detected quickly

without extensive seed preparation. X-rays can also detect the presence of multiple embryos. This method is difficult with very small seeds, but is used extensively with large seeded tree and shrub species and worked very well with most of the wildflower species used in this study.

TTC staining can be used effectively in combination with dissection, but embryo excision might be more useful in obtaining information on endogenous dormancy. TTC staining is more rapid than the embryo excision method.

Since legumes are widely used in agriculture much work has been done on establishing methods for breaking seed dormancy in this group. Dormancy in legumes is generally exogenous (due to seed coat structure) (Crocker & Barton 1953, Esau 1960, Barton 1965b, Villiers 1972, Brant *et. al.* 1971, Fahn 1974, Rolston 1978, Werker 1980/81). Seed coats are composed of an outer palisade layer made up of macrosclereids which have particularly thick outer walls and often covered with a waxy cuticle, a subepidermal layer of osteosclereids, and an inner parenchymatous layer (Esau 1960, Hayward 1967, Cutter 1971, Fahn 1974, Rolston 1978).

In a study of treatments of hard seeds of *Coronilla varia*, Brant *et. al.* (1971) found that removal of the cuticle by soaking seeds in organic solvents was not effective in increasing seed coat permeability. Similarly, Burns (1959) found that if seeds of *Lupinus angustifolius* were soaked in a dye, colour penetrated the cuticle but not the palisade layer. Effective pregermination treatments such

as mechanical abrasion, acid scarification and hot water soaking, resulted in disruption of the thick outer layer of macrosclereids (Brant *et. al.* 1971, Liu *et. al.* 1981). Since the macrosclereid layer is responsible for the impermeability of hard seeds, disruption of this layer is necessary before germination can proceed. Two methods were tested for their effectiveness in promoting germination of hard seeds: (1) hot water soaking, and (2) mechanical abrasion. Both treatments resulted in increased germination for most legumes, however, mechanical scarification was more effective than soaking. Abrading seed coats resulted in very high germination for most legumes.

A hard seed coat did not limit germination of either *Glycyrrhiza lepidota* or *Lupinus argenteus*. Germination percentages were lower in scarified seeds than in untreated seeds. Germination of *Lupinus argenteus* seeds soaked in hot water was also significantly lower than germination of untreated seeds. Stratification may have been required for complete germination or seeds may have been non-viable. Stratification, however, was detrimental to germination of *Glycyrrhiza lepidota*.

Hedysarum alpinum also required no abrasion, although some degree of hardseededness was present in seed lots, since seeds germinated in a shorter period of time following scarification. Stratification was detrimental to germination. Seeds which lacked hard coats and were harmed by stratification, may under natural conditions, germinate

soon after dissemination and overwinter as seedlings rather than as seeds. Barton (1965b) reported that hardseededness is related to many factors such as seed maturity, influence of climatic conditions at the time of seed formation, rate of drying, and storage conditions. Tests with seeds of these legumes after being retained for long periods of time may show that the seed coat becomes more impermeable with storage especially if conditions of moisture fluctuate (Villiers 1972, Barton 1965b). A higher percentage of hard seeds could be expected in natural situations because moisture conditions are more variable.

The most common type of dormancy in the Leguminosae, is physical, exogenous dormancy. This dormancy may also be combined with endogenous dormancy as observed in *Thermopsis rhombifolia*. Germination of *Thermopsis rhombifolia* increased with scarification indicating the presence of a hard seed coat. A second, endogenous dormancy is sometimes present, as suggested by increased germination percentages observed in seeds (collected in 1982) which were also stratified. A large number of seeds in seed lots of *Astragalus*, *Oxytropis*, and *Petalostemon* species were exogenously dormant. Disruption of the seed coats by abrasion resulted in extremely high germination percentages. Other types of dormancy were notably absent.

Hard seed coats are slowly broken down in nature through one or more of the following methods: by microbial action, by passage through animal digestive tracts, by the

scarifying effect of soil and sand particles, by exposure to high temperature, and/or by exposure to alternating cold and warm temperatures. Because these methods are not precise and depend on a number of factors and because some seeds are harder than others, germination is spread over time and not all seeds of a single plant germinate at one time.

Species other than legumes demonstrate exogenous dormancy in the form of a hard seed coat. The increase in germination observed for *Allium cernuum* and *Allium textile* following scarification indicate that these species are hardseeded. *Allium textile* also has an endogenous dormancy. Sorensen (1972) noted that the outer covering of seeds of *Allium* species appeared hard but if seeds were scarified no germination occurred. The disparity between results obtained in this study and those reported by Sorensen, might be due to the presence of an endogenous dormancy. Since seeds used by Sorensen were not scarified and stratified, the lack of germination which he observed, was likely due to a requirement for stratification.

Mechanical scarification was used effectively to overcome dormancy and increase permeability in a number of species which displayed physical, exogenous dormancy. Acid treatment may also be employed to increase permeability, but tests must be carried out prior to treatment to determine the most appropriate soaking period for various seed lots.

With the exception of *Senecio canus*, endogenous dormancy was found to be present, to some degree, in seed

lots of most Compositae. This can be seen by the increase in germination percentages or by the decrease in time to germinate for seeds which were stratified.

Each collection of *Achillea millefolium* displayed a high degree of endogenous dormancy and germination increased significantly when seeds were stratified. These results do not agree with observations made by Sorensen and Holden (1974). They found that 1 month of stratification did not increase the germination percentage nor decrease the time for germination to occur for *Achillea millefolium*. Both Sorensen and Holden, and Maguire and Overland (1959) obtained germination with percentages of 80% or higher with unstratified seeds. The latter authors did not specify the time period over which the germination tests were conducted and no indication of germination rate was given, therefore it is difficult to determine if there was indeed some dormancy which could have been overcome by stratification or if none existed. Villiers (1975) notes that the amount of dormancy can vary from population to population, depending on environmental conditions such as photoperiod, temperature, and moisture. Differences in results between studies might be due to this natural variation between populations. Results with *Achillea millefolium* support the observation that dormancy is often greater in seeds from more northern populations (Nikolaeva 1969).

Helianthus subrhomboideus seeds did not germinate unless stratified but after 2 months treatment, only 54%

germination was obtained. A second dormancy might be present in seeds of this species or seeds might require a longer stratification period (*i.e.* physical endogenous dormancy may be intermediate or deep rather than shallow).

Seeds lots of *Haplopappus spinulosus* and *Madia glomerata* exhibited some dormancy and germinated better and faster if stratified. *Hymenoxys richardsonii*, *Solidago rigida* and *Heterotheca villosa* all displayed varying amounts of endogenous dormancy as observed by either an increase in germination percentage or a decrease in the time required for germination, after pretreatment.

Results obtained with *Antennaria nitida* and *Gaillardia aristata* demonstrated that the amount of dormancy varied with each seed lot. Seed lots of *Arnica fulgens* collected in 1982, displayed some dormancy while results from seed lots collected in 1981 showed a tendency toward dormancy (there was a large variation among samples making the difference between stratified and untreated seeds results insignificant). Two of 3 seed lots of *Liatris punctata* showed small amounts of dormancy.

The preceeding examples suggest that the amount of endogenous dormancy in Compositae is variable. The amount and depth of this dormancy might be determined by environmental factors (temperature, photoperiod and moisture) prior to and following release from the parent plant, and to genetic differences in seeds from different parents. Barton (1965a) and Austin (1972) report that

dormancy periods are shorter for seeds which are produced during dry seasons than for those produced during wet seasons. This phenomenon may account for differences observed from year to year and for seeds collected at different sites.

A phenomenon which is reportedly common in the Compositae is seed polymorphism (Bewley and Black 1982). Polymorphic seeds are seeds which exhibit differences in size, shape and colour (somatic polymorphism) and/or differences in dormancy (*i.e.* seeds of a single plant fall into two discontinuous populations (Roberts 1972)). In Compositae, ray and disc flowers can produce different types of seeds. Seeds of *Grindelia squarrosa* appeared to be of 2 morphological types; one type being larger and more rounded than the other. A difference in dormancy between these apparently different seed types could account for the lower than expected germination percentages if the stratification period was only sufficient to overcome the dormancy in one type of seed. Further studies are needed to determine if these apparently different seeds can be separated into 2 distinct groups by their dormancy type.

Coreopsis tinctoria seeds failed to germinate if stratified but untreated seeds also germinated poorly. In the wild, this plant is often found in great masses in one year and then completely absent for several growing seasons (Looman and Best 1979). Since this annual relies on seeds for propagation, the observed lack of plants in some years

is likely due to seed dormancy. There are a number of possibilities for this variation in population from one year to the next: (1) an impermeable pericarp, (2) leachable inhibitors in the embryo or pericarp, or (3) a morphologically or physiologically immature embryo. Further tests with seeds of this species should include germination following the disruption of the pericarp, tests at regular intervals following harvest, tests following warm stratification, and tests after leaching seeds in running water. Kasper and McWilliams (1982) determined that germination of *Coreopsis tinctoria* occurred over a range of temperatures, from 15-35°C in the light, and found little or no dormancy. Seeds used by Kasper and McWilliams were obtained from a supplier and storage conditions prior to testing might have resulted in the removal of dormancy. Light might also stimulate germination.

Results of this study and those of other investigators (McGuire and Overland 1959, Pelton 1956, Sorensen and Holden 1974, Voight 1977) show that many Compositae (from temperate regions) exhibit some degree of endogenous dormancy but that most are not deeply dormant. Other types of dormancy such as those caused by impermeable coats, leachable inhibitors, and lack of suitable light, temperature, and moisture might be involved in the failure of seeds of certain species to germinate.

Morphologically immature embryos can be a cause of delayed germination in some members of the Umbelliferae.

(Austin *et. al.* 1969, Villiers 1972) and may be responsible for the poor germination performance of *Zizia aptera* and *Musineon divaricatum*. Greene and Curtis (1950) found that germination of *Zizia aptera* was poor if seeds were unstratified but following 5 months stratification germination greatly improved. This long period of stratification may be required for maturation of the embryo. Warm treatment would be more appropriate if embryos are morphologically immature. A long storage period overcame dormancy in few seeds.

Because seeds of *Zizia aptera* are dispersed soon after ripening and because all seeds from a single plant do not ripen at the same time, seeds in each collection varied in colour from brown to green. No differentiation was made in this study between completely brown seeds and those which were still somewhat green, since both appeared well developed and full. Although seeds were apparently viable, differences might have existed in the degree or type of dormancy exhibited by green or brown seeds. A comparison of germination of each colour may show some differences in their germination requirements (*i.e.* in environmental conditions or in type and duration of pretreatments).

For many species with indehiscent fruit, such as the schizocarp found in the Umbelliferae, inhibitors may be present in the outer covering of the fruit (Heydecker 1977). Since seeds of *Zizia aptera*, that had been soaked and rinsed in water prior to testing, failed to germinate, the presence

of a water-soluble inhibitor does not seem likely. Further evidence of the absence of soluble inhibitors is that water in which *Zizia* seeds had been soaked, did not hinder the germination of lettuce seeds. The pericarp and seed coat have no apparent hard layer of cells (such as the palisade layer in Leguminosae) which would restrict the movement of water into the embryo (FIGURE 3b). The innermost layer of the seed coat, however, appears waxy and may interfere with the movement of water into the embryo or the leaching of inhibitors from either the endosperm or embryo. To determine if dormancy of *Zizia aptera* and *Musineon divaricatum* is exogenous, embryos could be removed from the outer covering and tested for germination. If excised embryos germinate rapidly and completely, dormancy would be attributable to some property of the outer covering of the mericarp. If embryos fail to germinate, dormancy could then be considered (at least partially) endogenous and studies of the embryo could be undertaken to determine which factors are involved in maintaining dormancy.

Nichols (1934) observed little difference in germination between stratified and untreated seeds of both *Anemone cylindrica* and *Anemone multifida*. Greene and Curtis (1950) noted the same for *A. cylindrica* and *A. patens*, and these authors concluded that Ranunculaceae were unaffected by stratification. Results of this study agree with these findings. Germination was delayed one to several weeks even when a suitable environment for germination was provided.

Many species of the family Ranunculaceae (including some *Anemone* species) are reported to have rudimentary embryos when the seeds are shed from the parent plant (Bewley and Black 1982, Mayer and Poljakoff-Mayber 1982), and a period of afterripening is reportedly necessary prior to germination. If embryos are immature when the seeds are shed they may require several weeks or months of storage before germination occurs. This could not be determined from results reported here since all tests were carried out the spring and summer following collecting. To investigate this possibility, seed lots should be tested at weekly or biweekly intervals beginning shortly after harvest. It is likely that an afterripening is not necessary but that some changes take place following imbibition rather than in dry storage since seeds that were stored for up to six months prior to testing still required the one to several weeks at moist conditions before germination occurred. These changes probably proceed best at temperatures higher than 3-6°C since stratification did not decrease the time required for germination to occur. This may vary from population to population, however, since Sorensen (1972) found that stratification decreased the required time for germination for *Anemone cylindrica* and *Anemone patens*.

Yucca glauca seeds required no pretreatment and germinated in sufficient numbers to recommend the use of this species as a nursery plant. Some seeds of *Smilacina stellata* were dormant and required a stratification period

for maximum germination. Only 12% of the seeds collected in 1982 germinated. It is possible that this difference in germination could be attributed to differences in dormancy due to specific climatic conditions under which seeds were formed but more likely low germination was due to a high percentage of dead embryos (since many of the ungerminated seeds moulded).

Many rosaceaous seeds demonstrate endogenous dormancy and require long cold stratification periods for complete and normal germination (Mayer and Poljakoff-Mayber 1982). *Geum* species, however, require no pretreatment although some dormancy was present in seed lots of *Geum triflorum* as noted by the decrease in the time required for germination following stratification. Sorensen and Holden (1974) also found that germination pretreatments were not required for *Geum triflorum* seeds collected in South Dakota. Both *Geum aleppicum* and *Geum triflorum* exhibit great potential for further use as nursery plants because germination was found to be consistently high for all 3 collection years.

Some seeds of *Heuchera richardsonii* were dormant but the type of dormancy could not be determined from these studies. Physiological, endogenous dormancy was not indicated because a chilling period was detrimental to germination. Perhaps warm stratification would decrease the time required for germination and/or increase the germination percentage (*i.e.* seeds exhibit morphological endogenous dormancy). Dormancy may be imposed on seeds by

the test conditions (*i.e.* lack of light, unsuitable temperature). If seeds are light sensitive, maintaining seeds in the dark in an imbibed state might result in an induced dormancy. Seed coats might be hard or impermeable in which case they would benefit from scarification. That seeds of this species are harmed by stratification indicates that some could not survive cold winter temperatures. Seeds may germinate immediately after release and overwinter as seedlings rather than seeds.

Germination of *Oenothera biennis* increased after 2 months stratification with germination percentages being relatively high. Greene and Curtis (1950) found that neither untreated nor stratified seeds of *Oenothera biennis* germinated. It is reported that seeds of this species have a requirement for light (Kinzel 1926 as reported by Mayer and Poljakoff-Mayber 1982) but germination results from this study do not corroborate these findings. Although light might stimulate germination in some seeds under certain environmental conditions, no absolute requirement for light was noted.

Germination of *Monarda fistulosa* var. *menthifolia* varied with collections. Seeds of the 1980 collection were dormant as indicated by the increase in germination following stratification. High germination percentages indicate that this plant has good potential for commercial use.

Lithospermum ruderale seeds (actually nutlets) were very hard and germinated poorly. Either stratifying, or removing embryos from the pericarp, improved germination significantly, but germination percentages were still low. When removed from their covering, some of the embryos deteriorated quickly, an indication that the tissue was dead (Heit 1955). No evidence of the presence of soluble germination inhibitors was found since germination did not increase following soaking and rinsing seeds. The slight effect of soak-water on the germination of lettuce seeds may be an indication that a weak inhibitor is present, however, a weak inhibitor does not adequately account for the very poor germination. The thick outer layer of closely packed cells in the fruit coat may be effective in restricting the flow of water into the seeds, however, this also does not adequately explain the poor germination of *Lithospermum ruderale* seeds, and especially of embryos removed from the fruit coat. An in-depth study of germination of *Lithospermum ruderale* must include tests with excised embryos to determine if the embryos are dead or merely dormant. If dormant, tests must be undertaken to determine the type and cause of dormancy. Since neither stratifying (for up to 3 months) nor removing the embryos resulted in significant improvements in germination, several factors may combine to maintain dormancy. A combination of two or more treatments such as, removing embryos from the pericarp, rinsing them in water and stratifying them for various periods, may result

in greater germination for seeds of this species. Salisbury and Preston (1949) state that *Lithospermum* fruits are notorious for delayed germination; dormancy is often maintained for several years. These authors do not make recommendations as to the cause of dormancy nor the treatments required to overcome it. Possibly a prolonged afterripening period is required.

Two months cold stratification significantly increased germination of *Dodecatheon conjugens* seeds, however, germination percentages were still low. The seed coat is not a barrier to germination since scarification did not significantly increase germination over that obtained for untreated seeds. Other exogenous dormancy factors, such as inhibitors in the seed coat, might be present.

Both *Viola adunca* and *Arenaria congesta* var. *lithophila* seeds display some dormancy which can be overcome by stratification for 2 months. Seeds of the latter that did not germinate, did not sw[illegible] (were exogenously dormant) and should be scarified prior to testing.

Cleome serrulata seeds germinated best if stratified, however, germination percentages were extremely low. Because this is an annual species which is dependant on seeds to perpetuate itself from year to year, one would expect germination to be high. Heit (1946) working with *C. gigantea*, found that seeds germinated at 20-30°C if treated with 0.2% potassium nitrate under light conditions. The role of potassium nitrate in germination induction is not

completely understood, however, it is thought that it can replace the requirement for, or enhance the effect of, light on germination (Evenari 1965, Maguire 1972, MacKay 1972). Light (and/or KNO_3) might also be a requirement for germination of the native *Cleome*.

Seeds of *Eriogonum flavum* displayed some dormancy although not all seeds in a lot were dormant. Germination was good prior to stratification but this treatment was effective in breaking dormancy for seeds collected in 1981. Seeds of the 1982 collection germinated poorly and many were overgrown quickly with fungi.

Sisyrinchium montanum seeds were completely dormant. Although many Iridaceae species require a chilling period (Mayer and Poljakoff-Mayber 1982), 2 months stratification did not break dormancy. A longer stratification period may be necessary. Dormancy may be exogenous since the coat appeared hard. For some Iridaceae, inhibitors located in the seed coat are responsible for dormancy (Bewely and Black 1982). Removal of the seed coat may be an effective pretreatment for *Sisyrinchium*.

Germination of both cactus species was variable. Each seed lot of *Coryphantha vivipara* collected at the same site for 3 years reacted differently to stratification. Many of the seeds of the 1981 lot were dormant. The time of collection may have had a significant effect on the germination of *Coryphantha vivipara* seeds. Seeds collected in 1980 and 1981 were collected in late August and early

September, while those collected in 1982 were not collected until late September. Differences in climatic conditions (*e.g.* temperature and moisture) prior to harvest may account for varying amounts of dormancy. A longer (or shorter) period of stratification could be required. Seeds are not hard since many which failed to germinate had imbibed water during the test.

Seeds of *Opuntia polyacantha* germinated best if stratified, but germination was extremely low. Since the seed coats are thick and highly sclerified, dormancy might be due to an inability to take up water. If the outer coat of sclerified tissue or the cuticle layer were responsible for the inhibition of germination then the breakdown of these should lead to greater germination percentages. Scarification (acid or mechanical) did not increase germination to any significant degree. No evidence of the presence of soluble germination inhibitors was found. That the highest germination percentages were obtained with stratified seeds indicates that at least one type of dormancy is endogenous. Stratification combined with other treatments might be effective in breaking the dormancy. A period of alternating temperatures was partially effective in breaking dormancy in seeds of *Opuntia polyacantha*. Since no difference was noted between seeds placed in alternating temperatures for 3,4,5, or 6 weeks it would seem that only 3 weeks (or possibly less) is necessary. Improved germination performance might be observed if *Opuntia polyacantha* seeds

were given a short, single, warm stratification (*e.g.* 1-2 weeks) followed by a period of cold moist stratification (to overcome both a morphological and physiological dormancy).

Seeds of *Opuntia polyacantha* produce mucilage when placed in water. Mucilage, produced by seeds, may function in several different ways. It may serve to disperse the seeds, to orient the seeds on the germinating medium, to maintain moisture around the seeds or as a barrier to the diffusion of oxygen (in cases where excessive moisture is present) (Mayer and Shain 1974). *O. polyacantha* is a dryland species native to the most arid regions of Alberta and the production of mucilage might be an adaptation to prevent seeds from germinating in unsuitable locations (*i.e.* wet areas). To determine if seeds are sensitive to excessive moisture, a series of germination tests should be conducted on media of various water potentials.

Another species which produced mucilage when wetted was *Collomia linearis*. This annual species did not germinate if seeds were untreated or if stratified for 2 months. One would expect relatively high germination of these seeds since in the wild it is an early invader of disturbed open ground. Mucilage may be responsible for maintaining dormancy in these seeds, and may also be a result of excessive moisture conditions during testing. Light might also be required for germination of *Collomia* since in natural situations it grows on open areas.

Linum lewisii and *Plantago patagonica* seeds also produced mucilage upon wetting. For *Linum lewisii*, mucilage did not interfere with germination. These seeds displayed only a small amount of dormancy and this could have been either endogenous (since stratification decreased germination time) or imposed (since seeds germinated at low temperatures during treatment). This species should present no germination problems for nurserymen who wish to produce container plants. *Plantago patagonica* (tested for only one year) germinated best if seeds were untreated. Tolstead (1941) describes this species as a winter annual which germinates in the late summer or fall and overwinters as a seedling. The observed reduction in germination following stratification supports Tolstead's observation.

MaGuire and Overland (1959) concluded that seeds of species of the Scrophulariaceae germinate best if given alternating temperatures of 20 and 30°C and 4 weeks of moist chilling to increase germination percentages. Some variation from year to year was observed in the germination of *Penstemon* species. *Penstemon procerus* seeds were dormant, and this could be partially alleviated by 2 months cold stratification. *Penstemon nitidus* seeds also germinated best after stratification with 3 months of treatment more effective than 2 months. Neither of these species germinated beyond 65% and both might require a longer stratification. Tests for soluble inhibitors were negative for *P. nitidus*. The inner epidermis of the seed coat is thick-walled and

might inhibit some uptake of water.

Water-soluble germination inhibitors do not appear to play a role in the dormancy of *Besseya wyomingensis* since germination did not increase after soaking and rinsing seeds in water, nor did soak-water inhibit germination of lettuce seeds. The seed coat is probably not responsible for dormancy since removing this layer does not increase germination. Because the seed coat of *Besseya wyomingensis* is very thin one might expect it to provide little protection of the embryo and seeds might lose viability rapidly. This was not the case since seeds which were stored for 2 years, germinated well. Stratification for 2 or 3 months was the most effective treatment for breaking dormancy.

Germination requirements of seeds from wild populations can be highly variable, either within a single population or among different populations (Blake 1935). Differences in dormancy do not only occur among seeds collected from different plants but often among seeds collected from a single plant (Crocker and Barton 1953). The control of dormancy is probably a complex combination of genetic and environmental factors. Little information is available on the effects of specific environmental conditions prevalent during seed set and seed maturation, but factors such as low moisture, variation in temperatures and photoperiod, affect dormancy (Bewley and Black 1982). Other factors include the degree of maturity of the seeds when harvested and the

nature and duration of post-harvest storage. In spite of the large number of factors which are involved in the control of dormancy, uniform germination of seed lots can often be obtained by treating seeds. The beneficial effect of cold stratification, warm stratification, scarification, and seed soaking can be seen with various species in this study. Pregermination treatments are effective not only in increasing germination percentages and decreasing the time required for germination, but also in allowing seeds to germinate over a wider range of environmental conditions (Nikolaeva 1977, Baskin and Baskin 1979). This is especially important for nurserymen who must obtain maximum germination of seed lots in a short period of time. Other seed treatments might also be valuable for maximizing seed germination for the nurseryman. Preconditioning (priming, osmoconditioning) consists of soaking seeds in an osmotic solution of inorganic salts, sugars or polyethylene glycol at low water potentials for a period of 1 to 2 weeks (Khan 1980). The process shortens the time from sowing to emergence and is used to obtain plants and crops of uniform age and maturity. It increases the rate of germination and allows 'slow' seeds to germinate at the same time as 'fast' seeds in a seed lot (Khan 1980). It could be used to minimize the test time for variable seed lots especially those from wild populations.

V. CONCLUSIONS

The advantage of TTC staining as a test for viabiility is that it is rapid; results can be obtained in 24 hours. A disadvantage is that staining is often erratic and interpretation is extremely difficult. Interpretation is often a subjective determination of the condition of the embryo and not only based on the amount and location of the stain. Erratic staining might be due to reduced vitality of seeds or to differences in permeability of seed coverings. X-ray photos of seeds are rapid and seeds require no preparation. Irregularities in seeds such as broken or shriveled embryos and insect damage can be detected readily. Live and dead tissue can not readily be differentiated and with small seeds interpretation is difficult. In some cases, embryo excision might be a more appropriate test of viability since the presence of some dormancy types can be detected by this method.

Whether a species is worth growing commercially depends on many factors not on germination alone. The germination percentage above which large scale production is feasible is arbitrary and depends on such factors as seed availability. Species which germinated over 60%, however, show some potential for use in large scale production on the basis of germination alone. Of the 58 species tested, 42 germinated above 60% either with or without pretreatment. These species demonstrate good potential for commercial production on the basis of germination. For 9 species maximum germination

obtained was only between 30-60%. Further pretreatment is required either longer treatment periods or more than one treatment in combination. Seven species require further detailed investigation. The maximum germination of these species was less than 30% and commercial use would only be feasible if large numbers of seeds are available.

Recommendations for pretreatments are presented in TABLE 13, and were only given for species which germinated over 30%. Stratification improved germination percentages of 24 species and 2 other species were found to germinate sooner if stratified. These include 12 of the 15 species of Compositae, all 3 members of the Scrophulariaceae, and both species in the Cactaceae. Scarification was beneficial to germination of 11 of the 14 species of Leguminosae, and both *Allium* species (Liliaceae). Generally, members of the Leguminosae have impermeable seed coats (physical exogenous dormancy) and for some, endogenous dormancy can also be present. The members of both Ranunculaceae and Rosaceae germinated well and did not require stratification. *Geum triflorum* seeds, however, had some dormancy and stratification decreased the time of germination. Both Umbelliferae species (*Musineon divaricatum* and *Zizia aptera*) require further study before recommendations can be made as to the most appropriate treatment. There is some evidence that the embryos of *Zizia* are immature and require an extended afterripening period or warm stratification.

Certain taxonomic groups, such as those families discussed above, have characteristic dormancy types and respond to specific pregermination treatments. With different seed lots, dormancy in these families is probably modified to some extent by environmental conditions both during seed production and following seed dispersal. In some families, dormancy type and pretreatment requirements differ significantly among species. Each of 4 species of Liliaceae reacted differently to pretreatments. Untreated seeds of *Yucca glauca* germinated as well as stratified seeds but *Smilacina stellata* germinated best after stratification. *Allium cernuum* and *A. textile* have impermeable seed coats and disruption of the coat promotes germination. *Allium textile* and (possibly *A. cernuum*) respond positively to stratification in combination with scarification.

TABLE 14 Recommended pregermination treatments for seeds of native prairie wildflowers.

Species	Pregermination Treatment
Achillea millefolium	Stratification
Allium cernuum	Scarification
Allium textile	Scarification and Stratification
Anemone cylindrica	None Required
Anemone multifida	None Required
Anemone patens	Unknown
Antennaria nitida	Unknown[1]
Arenaria congesta var. *lithophila*	Stratification
Arnica fulgens	Stratification
Astragalus bisulcatus	Scarification
Astragalus crassicarpus	Scarification
Astragalus drummondii	Scarification[2]
Astragalus gilviflorus	Scarification
Astragalus pectinatus	Scarification
Astragalus striatus	Scarification
Besseya wyomingensis	Stratification
Cleome serrulata	Unknown
Collomia linearis	Unknown
Coreopsis tinctoria	Unknown
Coryphantha vivipara	Stratification
Dodecatheon conjugens	Stratification[2]
Eriogonum flavum	Stratification
Gaillardia aristata	Stratification
Geum aleppicum	None Required
Geum triflorum	None Required[3]
Glycyrrhiza lepidota	None Required[2]
Grindelia squarrosa	Stratification
Haplopappus spinulosus	Stratification
Hedysarum alpinum	None Required
Helianthus subrhomboideus	Stratification[2]
Heterotheca villosa	Stratification
Heuchera richardsonii	None Required
Hymenoxys richardsonii	Stratification
Liatris puntata	Stratification
Linum lewisii	None Required[3]
Lithospermum ruderale	Stratification[2]
Lupinus argenteus	None Required[2]
Madia glomerata	Stratification
Monarda fistulosa var. *menthifolia*	Stratification
Musineon divaricatum	Unknown
Oenothera biennis	Stratification
Opuntia polyacantha	Stratification[2]
Oxytropis monticola	Scarification
Oxytropis sericea var. *spicata*	Scarification
Penstemon nitidus	Stratification[2]

continued

TABLE 14 Recommended pregermination treatments for seeds of native prairie wildflowers.

Species	Pregermination Treatment
Penstemon procerus	Stratification
Petalostemon candidium	Scarification
Petalostemon purpureum	Scarification
Plantago patagonica var. *patagonica*	None Required
Ratibida columnifera	Stratification[2]
Senecio canus	None Required
Sisyrinchium montanum	Unknown
Smilacina stellata	Stratification
Solidago rigida	Stratification
Thermopsis rhombifolia	Scarification and Stratification
Viola adunca	Stratification
Yucca glauca	None Required
Zizia aptera	Unknown

[1] stratification might be detrimental for some seed lots.
[2] maximum germination between 30-60%.
[3] stratification increases germination rate.
[4] 3 months stratification.

BIBLIOGRAPHY

1 AMEN, R. D. 1963. The concept of seed dormancy. Amer. Sci. 51:409-424.

2 ASSOCIATION OF OFFICIAL SEED ANALYSTS. 1970. Tetrazolium testing handbook for agricultural seeds. Edited by D. F. Grabe. Assoc. of Offic. Seed Analysts. 62 pp.

3 ASSOCIATION OF OFFICIAL SEED ANALYSTS. 1978. Rules for testing seed. Jour. Seed Technol. 3(3):1-152.

4 AUSTIN, R. B. 1972. Effects of environment before harvesting on viability. In Viability of seeds. Edited by E. H. Roberts. Chapman and Hall Ltd., London. pp. 114-149.

5 AUSTIN, R. B., P. C. LONGDEN and J. HUTCHINSON. 1969. Some effects of 'hardening' carrot seed. Ann. Bot. 33:883-895.

6 BARTON, R. B. 1965a. General survey of dormancy types in seeds and dormancy imposed by external agents. In Encyclopaedia of plant physiology. Edited by W. Ruhland. Springer-Verlag, Berlin. 15(2):699-720.

7 BARTON, R. B. 1965b. Dormancy in seeds imposed by the seed coat. In Encyclopaedia of plant physiology. Edited by W. Ruhland. Springer-Verlag, Berlin. 15(2):727-745.

8 BASKIN, J. M. and C. C. BASKIN. 1979. The germination strategy of oldfield aster (*Aster pilosus*). Amer. J. Bot. 66:1-5.

9 BENCHLEY, W. E. and K. WARINGTON. 1930. The weed seed population in arable soil. Jour. Ecol. 18:235-272.

10 BEWLEY, J. D. and M. BLACK 1982. Physiology and biochemistry of seeds in relation to germination. Volume II. Springer-Verlag. New York.

11 BIBBEY, R. O. 1948. Physiological studies of weed seed germination. Plant Physiol. 23(4):467-484.

12 BLAKE, A. K. 1935. Viability and germination of seeds and early life history of prairie plants. Ecol Mono. 5:405-460.

13 BONNER, F. T., B. F. MCLEMORE and J. P. BARNETT. 1974. Presowing treatment of seed to speed germination. In Seeds of woody plants of the United States. Edited by C. S. Schopmeyer. U.S. Dept. Agric. For. Serv., Washington D.C., Agricultural Handbook No. 450. pp. 126-135.

14 BONNER, F. T. 1974. Seeds testing. In Seeds of woody plants of the United States. Edited by C. S. Schopmeyer. U.S. Dept. Agric. For. Serv., Washington D.C., Agricultural Handbook No. 450. pp. 136-152.

15 BRANT, R. E., G. W. McKEE and R. W. CLEVELAND. 1971. Effect of chemical and physical treatments on hard seeds of penngift crownvetch. Crop Sci. 11:1-6.

16 BURNS, R. E. 1959. Effect of acid scarification on lupin seed impermeability. Plant Physiol. 34:107-108.

17 CANADA DEPARTMENT OF AGRICULTURE. 1979. Methods and procedures for testing seeds. Seed Biol. Lab., Lab. Serv. Div., Ottawa, Ont. 136 pp.

18 COTTRELL, H. J. 1948. Tetrazolium salt as a seed germination indicator. Ann. Appl. Biol. 35:123-131.

19 CROCKER, W. and L. V. BARTON. 1953. Physiology of seeds. Chronica Botanica Company. Waltham, Mass. 267 pp.

20 CURRAH, R. S., A. SMRECIU and M. VAN DYK. 1982. Phase II: revegetation study. The Friends of the University of Alberta Devonian Botanic Garden, Edmonton. Prep. for Alberta Environment. 92 pp.

21 CUTTER, E. G. 1971. Plant anatomy: experiment and interpretation. Part 2: organs. Edward Arnold, London. pp 264-271.

22 ESAU, K. 1960. Anatomy of seed plants. John Wiley & Sons, Inc. New York. pp. 326-335.

23 EVENARI, M. 1965. Light and seed dormancy. In Encyclopaedia of plant physiology. Edited by W. Ruhland. Springer-Verlag, Berlin. 15(2):804-847.

24 FAHN, A. 1974. Plant anatomy. 2nd Edition. Pergamon Press. Toronto. 611 pp.

25 GORDON, A. G. and D. C. F. ROWE. 1982. Seed manual for ornamental trees and shrubs. Forestry Commission Bulletin No. 59. Her Majesty's Stationary Office. London. 132 pp.

26 GREENE, H. C. and J. T. CURTIS. 1950. Germination studies of Wisconsin prairie plants. Amer. Mid. Nat. 43:186-194.

27 GRISWOLD, S. M. 1936. Effect of alternate moistening and drying on seeds of western range plants. Botan. Gaz. 98:243-269.

28 HARTMANN H. T. and D. E. KESTER 1959. Plant propagation: principles and practices. Prentice Hall Inc., New Jersey. 662 pp.

29 HAYWARD, H. E. 1967. The structure of economic plants. MacMillian Co. New York. 647 pp.

30 HEIT, C. E. 1946. Laboratory germination results with certain flower seeds. Proc. Assoc. of Official Seed Analysts. 36th Annual Meeting. pp. 141-149.

31 HEIT, C. E. 1955. The excised embryo method for testing germination quality of dormant seed. Proc. Assoc. of Official Seed Analysts. pp. 108-117.

32 HELLUM, K. 1983. Personal communication. Department of Forest Science. University of Alberta.

33 HEYDECKER, W. 1977. Stress and seed germination: an agronomic view. In The physiology and biochemistry of seed dormancy and germination. Edited by A. A. Khan. North-Holland Publishing Co., New York. pp. 237-282.

34 HOFFMAN, G. R., M. B. HOGAN and L. D. STANLEY. 1980. Germination of plants species common to reservoir shores in the northern great plains. Bull. Torrey Bot. Club 107(4):506-513.

35 INTERNATIONAL SEED TESTING ASSOCIATION. 1966. International rules for seed testing. Proc. Intern. Seed Testing Assoc. 31:1-152.

36 JOHANSEN, D. A. 1940. Plant microtechnique. McGraw Hill, New York. 523 pp.

37 JUSTICE, O. L. 1972. Essentials of seed testing. In Seed biology. Volume III. Edited by T. T. Kozlowski. Academic Press, New York. pp. 301-370.

38 KASPER, M. J. and E. L. MCWILLIAMS 1982. Effects of temperature on the germination of selected wildflower seeds, Hortscience 17(4):595-596.

39 KESTER, D. E. 1960. Seed dormancy and its relationship to nursery practices. Proc. Plant Prop. Soc. pp. 256-267.

40 KHAN, A. A. 1980. Preconditioning, germination and performance of seeds. In The physiology and biochemistry of seed dormancy and germination. Edited by A. A. Khan. North-Holland Publishing Co., New York. 547 pp.

41 KOLLER, D. 1972. Environmental control of seed germination. In Seed biology. Volume II. Edited by T. T. Kozlowski. Academic Press, New York. pp. 1-101.

42 KRUGMAN, S. L., W. I. STEIN and D. M. SCHMITT. 1974. Seed biology. In Seeds of woody plants of the United States. Edited by C. S. Schopmeyer. U.S. Dept. Agric. For. Serv., Washington D.C., Agricultural Handbook No. 450. pp. 5-33.

43 LAKON, G. 1949. The topographical tetrazolium method for determining the germinating capacity of seeds. Plant Physiol. 24:389-394.

44 LEWAK, S. and R. M. RUDNICKI. 1977. After-ripening in cold-requiring seeds. In The physiology and biochemistry of seed dormancy and germination. Edited by A. A. Khan. North-Holland Publishing Co., New York. pp. 193-217.

45 LOOMAN, J. and K. F. BEST. 1979. Budd's flora of the canadian prairie provinces. Research Branch, Agriculture Canada. Pub. No. 1662. 863 pp.

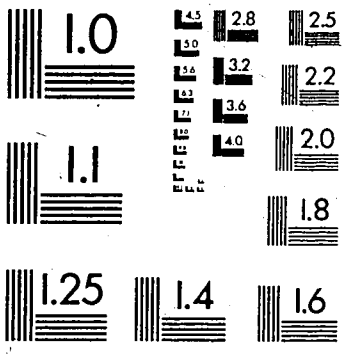
46 LIU, N. Y., H. KHATAMIAN and T. A. FRETZ. 1981. Seed coat structure of three woody legume species after chemical and physical treatments to increase germination. J. Amer. Hort. Sci. 106(5):691-694.

47 MACKAY, D. B. 1972. The measurement of viability. In Viability of seeds. Edited by E. H. Roberts. Chapman and Hall Ltd., London. pp. 172-208.

48 MAGUIRE, J. D. and A. OVERLAND. 1959. Laboratory germination of seeds of weedy and native plants. Wash. Agric. Exp. Stn. Circ. 349. 15 pp.

49 MAGUIRE, J. D. 1972. Physiological disorders in germinating seeds induced by the environment. In Seed ecology. Edited by W. Heydecker. Butterworth & Co. Ltd., London. pp. 289-310.

50 MAYER, A. M. and A. POLJAKOFF-MAYBER. 1982. The germination of seeds. 3rd Edition. Pergamon Press, Toronto. 211 pp.



51 MAYER, A. M. and Y. SHAIN. 1974. Control of seed germination. Ann. Rev. Plant Physiol. 25:167-193.

52 MOORE, R. P. 1962. Tetrazolium as a universally accepted quality test of viable seed. Proc. Intern. Seed Testing Assoc. 27:795-805.

53 MOORE, R. P. 1973. Tetrazolium staining for assessing seed quality. In Seed ecology. Edited by W. Heydecker. Butterworth & Co. Ltd., London. pp. 347-366.

54 NICHOLS, G. E. 1934. The influence of exposure to winter temperatures upon seed germination in various native american plants. Ecology 15(4):364-373.

55 NIKOLAEVA, M. G. 1969. Physiology of deep dormancy in seeds. National Science Foundation, Wash. D. C. 220 pp.

56 NIKOLAEVA, M.G. 1977. Factors controlling the seed dormancy pattern. In The physiology and biochemistry of seed dormancy and germination. Edited by A. A. Khan. North-Holland Publishing Co., New York. pp. 51-74.

57 PACKER, J. G. 1983. Flora of Alberta. by E.H. Moss. 2nd edition. University of Toronto Press. Toronto. 687 pp.

58 PELTON, J. 1956. A study of seed dormancy in eighteen species of high altitude Colorado plants. Butler U. Bot. Studies. 13:74-84.

59 POLLOCK, B. M. and V. K. TOOLE. 1961. Afterripening, rest period and dormancy. In Seeds: The yearbook of agriculture. U. S. Dept. Agric., Wash. D.C. pp. 106-112.

60 ROBERTS, E. H. 1972. Dormancy: a factor affecting seed survival in the soil. In Viability of seeds. Edited by E. H. Roberts. Chapman and Hall Ltd., London. pp. 321-359.

61 ROLSTON, M. P. 1978. Water impermeable seed dormancy. Bot. Rev. 44(3):365-396.

62 SABO, D. G, G. V. JOHNSON, W. C. MARTIN and E. F. ALDON. 1979. Germination requirements of 19 species of arid land plants. U. S. Dep. Agric. For. Serv., Res. Paper RM-210, Rocky Mtn. For. and Range Expt. Stn., Fort Collins, Colo. 26 pp.

63 SALAC, S. S. and M. C. HESSE 1975. Effects of storage and germination conditions on the germination of four species of wildflowers. J. Amer. Hort. Sci. 100(4):359-361.

64 SALISBURY, E. J. and G. H. PRESTON. 1949. Note on fruit size and viability in *Lithospermum officiale*. Kew Roy. Botan. Gardens Bull. 2:153-155.

65 SORENSEN, J. T. and D. J. HOLDEN. 1974. Germination of native prairie forbs. J. Range Manage. 27(2):123-126.

66 SORENSEN, J. T. 1972. Germination and vegetative propagation of native prairie forbs. MSc. Thesis. South Dakota State University.

67 TOLSTEAD, W. L. 1941. Germination habits of certain sandhill plants in Nebraska. Ecology 22:393-397.

68 VILLIERS, T. A. 1972. Seed dormancy. In Seed biology. Volume II. Edited by T. T. Kozlowski. Academic Press, New York. pp. 219-281.

69 VILLIERS, T. A. 1975. Dormancy and the survival of plants. Edward Arnold (Publishers) Ltd. London. 67 pp.

70 VOIGHT, J. W. 1977. Seed germination of true prairie forbs. J. Range Manage. 30(6):439-441.

71 WARING, P. F. 1969. Germination and dormancy. In The physiology of plant growth and development. Edited by M. B. Wilkins. McGraw- Hill, Toronto. pp. 605-644.

72 WARING, P. F., J. VAN STADEN and D. P. WEBB. 1973. Endogenous hormones in the control of seed dormancy. In Seed ecology. Edited by W. Heydecker. Butterworth & Co. Ltd., London. pp. 145-155.

73 WATSON, L. E., R. W. PARKER and D. F. POLSTER. 1980. Manual of plant species suitability for reclamation in Alberta. Volume II. Techman Ltd. Prep. for Land Conservation and Reclamation Council of Alberta. 541 pp. + appendices.

74 WERKER E 1980/81. Seed dormancy as explained by the anatomy of embryo envelopes. Is. J. Bot. 29:22-44.

APPENDIX 1 SEED COLLECTION

SPECIES	YEAR	LOCATION
Achillea millefolium	1980	Onefour
	1981	Milk River Ridge
	1982	Milk River Ridge
Allium cernuum	1980	Devonian Botanic Garden
Allium textile	1981	Milk River Ridge
	1982	Milk River Ridge
Anemone cylindrica	1980	Jensen Reservoir
	1981	Bullshead
	1982	Elkwater Lake
Anemone multifida	1980	Michel Reservoir
	1981	Elkwater Lake
	1982	Elkwater Lake
Anemone patens	1980	Elkwater Lake
Antennaria nitida	1980	Michel Reservoir
	1981	Michel Reservoir
	1982	Milk River Ridge
Arenaria congesta var. *lithophila*	1980	Elkwater Lake
Arnica fulgens	1981	Bare Creek Reservoir
	1982	Bare Creek Reservoir
Astragalus bisulcatus	1980	Cressday
	1981	Milk River Ridge
Astragalus crassicarpus	1981	Cressday
	1982	Milk River Ridge
Astragalus drummondii	1981	Milk River Ridge
Astragalus gilviflorus	1981	Jensen Reservoir
Astragalus pectinatus	1980	Bullshead
	1981	Bullshead
	1982	Milk River Ridge
Astragalus striatus	1980	Elkwater Lake
	1981	Michel Reservoir
	1982	Bare Creek Reservoir
Besseya wyomingensis	1980	Elkwater Lake
	1981	Milk River Ridge
	1982	Milk River Ridge
Cleome serrulata	1980	Pollockville
Collomia linearis	1980	Cypress View Reservoir
Coreopsis tinctoria	1980	Cypress View Reservoir
Coryphantha vivipara	1980	Milk River Ridge
	1981	Milk River Ridge
	1982	Milk River Ridge
Dodecatheon conjugens	1980	Milk River Ridge
	1981	Milk River Ridge
	1982	Milk River Ridge
Eriogonum flavum	1981	Michel Reservoir
	1982	Milk River Ridge
Gaillardia aristata	1980	Bullshead

continued

APPENDIX 1 SEED COLLECTION

SPECIES	YEAR	LOCATION
	1981	Elkwater Lake/Milk River Ridge
	1982	Milk River Ridge
Geum aleppicum	1980	Michel Reservoir
	1981	Bullshead
	1982	Bullshead
Geum triflorum	1980	Bullshead
	1981	Bare Creek Reservoir
	1982	Bare Creek Reservoir
Glycyrrhiza lepidota	1981	Bare Creek Reservoir
Grindelia squarrosa	1980	Milk River Ridge
	1981	Michel Reservoir
	1982	Milk River Ridge
Haplopappus spinulosus	1981	Bullshead
Hedysarum alpinum	1980	Devonian Botanic Garden
	1981	Cypress Hills
	1982	Cypress Hills
Helianthus subrhomboideus	1981	Elkwater Lake
Heterotheca villosa	1980	Little Bow Reservoir
	1981	Little Bow Reservoir
	1982	Milk River Ridge
Heuchera richardsonii	1980	Michel Reservoir
	1981	Bullshead
	1982	Bullshead
Hymenoxys richardsonii	1980	Jensen Reservoir
	1981	Bare Creek Reservoir
	1982	Milk River Ridge
Liatris punctata	1980	Milk River Ridge
	1981	Jensen Reservoir
	1982	Jensen Reservoir
Linum lewisii	1980	Devonian Botanic Garden
	1981	Jensen Reservoir
	1982	Jensen Reservoir
Lithospermum ruderale	1980	Elkwater Lake
	1981	Milk River Ridge
	1982	Milk River Ridge
Lupinus argenteus	1980	Elkwater Lake
Madia glomerta	1980	Bare Creek Reservoir
Monarda fistulosa var. *menthifolia*	1980	Elkwater Lake
	1981	Elkwater Lake
Musineon divaricatum	1980	Bullshead
	1981	Jensen Reservoir
Oenothera biennis	1980	Elkwater Lake
	1981	Elkwater Lake
	1982	Milk River Ridge
Opuntia polyacantha	1980	Cressday
	1981	Cressday

continued

APPENDIX 1 SEED COLLECTION

SPECIES	YEAR	LOCATION
	1982	Cressday
Oxytropis monticola	1980	Elkwater Lake
	1981	Cypress Hills
	1982	Cypress Hills
Oxytropis sericea var. *spicata*	1981	Bare Creek Reservoir
	1982	Bare Creek Reservoir
Penstemon nitidus	1980	Elkwater Lake
	1981	Cypress View Reservoir
	1982	Milk River Ridge
Penstemon procerus	1980	Elkwater Lake
	1981	Cypress Hills
	1982	Cypress Hills
Petalostemon candidum	1980	Milk River Ridge
Petalostemon purpureum	1981	Jensen Reservoir
Plantago patagonica var. *patagonica*	1980	Cressday
Ratibida columnifera	1980	Cypress View Reservoir
Senecio canus	1981	Jensen Reservoir
Sisyrinchium montanum	1981	Cypress View Reservoir
Smilacina stellata	1980	Elkwater Lake
	1981	Elkwater Lake
	1982	Elkwater Lake
Solidago rigida	1980	Elkwater Lake
	1981	Bullshead
Thermopsis rhombifolia	1980	Cypress View Reservoir
	1981	Cypress View Reservoir
	1982	Milk River Ridge
Viola adunca	1980	Devonian Botanic Garden'
Yucca glauca	1981	Lost River Canyon
Zizia aptera	1980	Bullshead
	1981	Cypress Hills
	1982	Cypress Hills

'grown in cultivation

APPENDIX 2 GERMINATION OF SEED LOTS OF 58 SPECIES WITH AND WITHOUT PRETREATMENTS.
For each collection, means followed by a different letter are significantly different for P<0.05.

Collection	Treatment	No. of Replicates and Seeds/Rep.	Germination Mean ±SD		Days to Germinate
Achillea millefolium (1980)	Control	4 x 25	8.25± 4.11	a	2-29
	Stratification	4 x 25	19.25± 3.78	b	1-12
Achillea millefolium (1981)	Control	4 x 100	21.50± 4.43	a	2-20
	Stratification	4 x 100	63.70± 4.11	b	1-16
Achillea millefolium (1982)	Control	4 x 100	39.50± 7.85	a	3-26
	Stratification	4 x 100	76.50± 5.20	b	to 29
Allium cernuum (1980)	Control	4 x 25	2.25± 1.71	a	5-28
	Stratification	4 x 25	6.50± 1.73	b	2-30
	Scarification	4 x 25	22.00± 1.16	c	1-15
Allium textile (1981)	Control	4 x 100	6.75± 1.26	a	4-30
	Stratification	4 x 100	27.57± 3.87	b	to 30
	Scarification	4 x 100	62.50± 7.42	c	1-11
	Scar./ Strat.	4 x 100	81.75± 0.50	d	to 22
Allium textile (1982)	Control	4 x 100	4.25± 1.89	a	3-30
	Stratification	4 x 100	18.50± 4.43	b	to 27
	Scarification	4 x 100	9.00± 4.55	ab	1-29
	Scar./ Strat.	4 x 100	44.25±14.59	c	to 7
Anemone cylindrica (1980)	Control	4 x 25	18.50± 3.00	a	16-30
	Stratification	4 x 25	17.50± 2.52	a	14-28
Anemone cylindrica (1981)	Control	4 x 100	71.75±19.10	a	11-30
	Stratification	4 x 100	74.75±11.10	a	12-30
Anemone multifida (1980)	Control	4 x 25	2.75± 1.71	a	17-30
	Stratification	4 x 25	0.50± 1.00	a	20-27
Anemone multifida (1981)	Control	4 x 100	84.50± 8.95	a	12-30
	Stratification	4 x 100	86.00± 8.29	a	12-30
Anemone multifida	Control	4 x 100	83.25± 8.95	a	11-29

continued

APPENDIX 2 GERMINATION OF SEED LOTS OF 58 SPECIES WITH AND WITHOUT PRETREATMENTS.
For each collection, means followed by a different letter are significantly different for P<0.05.

Collection	Treatment	No. of Replicates and Seeds/Rep.	Germination Mean ±SD		Days to Germinate
(1982)	Stratification	4 x 100	82.00± 6.13	a	8-29
Anemone patens (1980)	Control	4 x 25	2.50± 1.00	a	16-30
	Stratification	4 x 25	0.25± 0.50	b	29
Antennaria nitida (1980)	Control	2 x 25	2.50± 0.71		3-27
Antennaria nitida (1981)	Control	4 x 100	16.25± 2.63	a	3-30
	Stratification	4 x 100	87.50± 3.11	b	to 22
Antennaria nitida (1982)	Control	4 x 100	100.00± 0.00	a	2-7
	Stratification	4 x 100	92.25± 2.63	b	to 30
Arenaria congesta var. *lithophila* (1980)	Control	4 x 25	13.75± 1.71	a	1-27
	Stratification	4 x 25	17.75± 2.22	b	to 14
Arnica fulgens (1981)	Control	4 x 100	79.00± 4.08	a	3-27
	Stratification	4 x 100	91.00±10.68	a	to 25
Arnica fulgens (1982)	Control	4 x 100	64.25± 3.86	a	4-28
	Stratification	4 x 100	98.25± 0.96	b	to 10
Astragalus bisulcatus (1980)	Control	4 x 25	1.00± 0.82	a	1-28
	Scarification	4 x 25	19.00± 3.16	b	1-29
	Hot Water	4 x 25	9.75± 1.50	c	2-30
Astragalus bisulcatus (1981)	Control	4 x 100	23.25± 7.41	a	1-30
	Stratification	4 x 100	26.00± 6.38	a	to 28
	Scarification	4 x 100	93.25± 4.99	b	1-23
	Scar./ Strat.	4 x 100	90.00± 0.82	b	to 8
Astragalus crassicarpus (1981)	Control	2 x 100	11.00± 4.24	a	3-28
	Stratification	2 x 100	7.00± 1.41	a	to 30
	Scarification	2 x 100	97.00± 0.00	b	1-14

continued

APPENDIX 2 GERMINATION OF SEED LOTS OF 58 SPECIES WITH AND WITHOUT PRETREATMENTS.
For each collection, means followed by a different letter are significantly different for P<0.05.

Collection	Treatment	No. of Replicates and Seeds/Rep.	Germination Mean ±SD		Days to Germinate
Astragalus crassicarpus (1982)	Control	2 x 100	10.50± 0.71	a	3-23
	Stratification	2 x 100	13.50± 2.12	a	to 13
	Scarification	2 x 100	100.00± 0.00	b	3-30
	Scar./ Strat.	2 x 100	80.00± 4.24	c	
Astragalus drummondii (1981)	Control	4 x 100	4.50± 1.91	a	2-30
	Stratification	4 x 100	7.50± 1.91	a	to 25
	Scarification	4 x 100	55.25±10.78	b	1-13
	Scar./ Strat.	4 x 100	40.25± 4.92	c	to 23
Astragalus gilviflorus (1981)	Control	2 x 100	32.50±10.61	a	2-28
	Scarification	2 x 100	92.00± 5.66	b	1-30
Astragalus pectinatus (1980)	Control	4 x 25	7.25± 2.75	a	2-30
	Scarification	2 x 21	19.00		1-28
	Hot Water	4 x 25	18.75± 5.19	b	2-29
Astragalus pectinatus (1981)	Control	4 x 100	20.50± 5.00	a	1-30
	Stratification	4 x 100	7.00± 2.16	b	to 29
	Scarification	4 x 100	94.75± 4.35	c	1-14
	Scar./ Strat.	4 x 100	89.00± 6.83	c	to 5
Astragalus pectinatus (1982)	Control	2 x 100	0.00± 0.00	a	----
	Stratification	2 x 100	0.00± 0.00	a	----
	Scarification	2 x 100	0.50± 0.71	a	2
	Scar./ Strat.	2 x 100	0.00± 0.00	a	----
Astragalus striatus (1980)	Control	4 x 25	2.75± 0.96	a	1-29
	Scarification	4 x 25	24.25± 0.96	b	1-24
	Hot Water	4 x 25	11.75± 2.50	c	1-29
Astragalus striatus (1981)	Control	4 x 100	8.50± 1.29	a	1-29
	Stratification	4 x 100	19.25± 1.71	b	to 30
	Scarification	4 x 100	99.25± 1.50	c	1-5
	Scar./ Strat.	4 x 100	84.50± 4.51	d	to 28

continued

APPENDIX 2 GERMINATION OF SEED LOTS OF 58 SPECIES WITH AND WITHOUT PRETREATMENTS.
For each collection, means followed by a different letter are significantly different for P<0.05.

Collection	Treatment	No. of Replicates and Seeds/Rep.	Germination Mean ±SD		Days to Germinate
Astragalus striatus (1982)	Control	2 x 100	20.00±14.14	a	1-29
	Stratification	2 x 100	3.00± 2.83	a	to 17
	Scarification	2 x 100	80.00± 4.24	b	1-5
	Scar./ Strat.	2 x 100	78.00± 4.24	b	to 4
Besseya wyomingensis (1980)	Control	4 x 25	0.00± 0.00	a	----
	Stratification	4 x 25	0.50± 1.00	a	7
Besseya wyomingensis (1981)	Control	4 x 100	0.25± 0.50	a	26-30
	Stratification	4 x 100	2.25± 0.96	b	2-9
	Scarification	4 x 100	0.50± 0.58	a	17-21
Besseya wypmingensis (1982)	Control	4 x 100	2.25± 1.71	a	11-26
	Strat. 2mo	4 x 100	63.75± 6.55	b	to 30
	Strat. 3mo	4 x 100	72.00± 4.55	c	to 13
	Hot Water	4 x 100	0.00± 0.00	a	----
Besseya wyomingensis (1981)?	Control	4 x 100	2.25± 1.89	a	11-28
	Strat. 2mo	4 x 100	78.75±10.53	b	to 24
	Strat. 3mo	4 x 100	82.25± 4.35	b	to 21
Cleome serrulata (1980)	Control	4 x 25	0.75± 0.50	a	19-22
	Stratification	4 x 25	5.00± 2.00	b	to 1?
Collomia linearis (1980)	Control	4 x 25	0.00± 0.00	a	----
	Stratification	4 x 25	0.00± 0.00	a	----
Coreopsis tinctoria (1980)	Control	4 x 25	0.25± 0.50	a	2
	Stratification	4 x 25	0.00± 0.00	a	----
Coryphantha vivipara (1980)	Control	4 x 25	18.00± 1.41	a	4-26
	Stratification	4 x 25	19.25± 2.50	a	4-12
Coryphantha vivipara (1981)	Control	4 x 100	3.75± 3.77	a	7-21
	Stratification	4 x 100	24.25± 7.93	b	4-30

continued

APPENDIX 2 GERMINATION OF SEED LOTS OF 58 SPECIES WITH AND WITHOUT PRETREATMENTS.
For each collection, means followed by a different letter are significantly different for P<0.05.

Collection	Treatment	No. of Replicates and Seeds/Rep.	Germination Mean ±SD		Days to Germinate
Coryphantha vivipara (1982)	Control	4 x 100	0.50± 1.00	a	8-13
	Stratification	4 x 100	0.75± 0.50	a	6-18
Dodecatheon conjugens (1980)	Control	4 x 25	0.00± 0.00	a	----
	Stratification	4 x 25	1.25± 1.50	a	to 23
Dodecatheon conjugens (1981)	Control	4 x 100	0.75± 0.96	a	21-27
	Stratification	4 x 100	31.25± 4.27	b	to 29
	Scarification	4 x 100	1.50± 1.00	a	1-29
Dodecatheon conjugens (1982)	Control	4 x 100	0.00± 0.00	a	----
	Stratification	4 x 100	15.50± 8.54	b	to 14
Eriogonum flavum (1981)	Control	2 x 100	87.50± 0.71	a	1-28
	Stratification	2 x 100	97.50± 0.71	b	to 13
Eriogonum flavum (1982)	Control	4 x 100	31.00± 2.83	a	4-30
	Stratification	4 x 100	46.50±13.44	a	to 28
Gaillardia aristata (1980)	Control	4 x 25	19.50± 3.87	a	2-15
	Stratification	4 x 25	17.00± 4.16	a	to 10
Gaillardia aristata[3] (1981)	Control	4 x 100	80.50± 6.66	a	3-30
	Stratification	2 x 100	92.00± 1.41	a	2-24
Gaillardia aristata[4] (1981)	Control	4 x 100	57.50±14.50	a	3-30
	Stratification	2 x 100	39.50± 4.90	a	2-23
Gaillardia aristata[4] (1982)	Control	4 x 100	46.00± 9.66	a	4-29
	Stratification	4 x 100	63.75± 3.30	b	to 7
Geum aleppicum (1980)	Control	4 x 25	24.50± 0.58	a	4-6
	Stratification	4 x 25	25.00± 0.00	a	to 4
Geum aleppicum	Control	4 x 100	99.75± 0.50	a	4-12

continued

APPENDIX 2 GERMINATION OF SEED LOTS OF 58 SPECIES WITH AND WITHOUT PRETREATMENTS.
For each collection, means followed by a different letter are significantly different for P<0.05.

Collection	Treatment	No. of Replicates and Seeds/Rep.	Germination Mean ±SD		Days to Germinate
(1981)	Stratification	4 x 100	100.00± 0.00	a	2-6
Geum aleppicum (1982)	Control	4 x 100	99.50± 0.58	a	5-17
	Stratification	4 x 100	100.00± 0.00	a	1-16
Geum triflorum (1980)	Control	4 x 25	23.75± 0.96	a	4-9
	Stratification	4 x 25	24.00± 1.41	a	to 8
Geum triflorum (1981)	Control	4 x 100	97.00± 2.16	a	4-28
	Stratification	4 x 100	98.75± 1.50	a	1-8
Geum triflorum (1982)	Control	4 x 100	97.25± 2.63	a	5-29
	Stratification	4 x 100	98.50± 1.29	a	to 19
Glycyrrhiza lepidota (1981)	Control	4 x 100	31.00±12.99	a	2-30
	Stratification	4 x 100	0.75± 1.50	b	9-26
	Scarification	4 x 100	11.50± 5.51	bc	2-29
	Scar./Strat.	4 x 100	14.00± 6.73	c	to 19
Grindelia squarrosa (1980)	Control	4 x 25	1.50± 1.00	a	5-26
	Stratification	4 x 25	0.75± 0.96	a	2-5
Grindelia squarrosa (1981)	Control	4 x 100	11.25± 4.50	a	2-30
	Stratification	4 x 100	64.25± 6.50	b	to 15
Grindelia squarrosa (1982)	Control	4 x 100	5.25± 2.22	a	3-29
	Stratification	4 x 100	29.50± 8.58	b	to 30
Haplopappus spinulosus (1981)	Control	4 x 100	85.50± 9.42	a	2-15
	Stratification	4 x 100	95.00± 2.94	b	to 8
Hedysarum alpinum (1980)	Control	4 x 25	23.00± 1.15	a	1-30
	Scarification	4 x 25	25.00± 0.00	a	1-10
	Hot Water	4 x 25	19.50± 3.11	b	1-27
Hedysarum alpinum	Control	4 x 100	98.50± 1.29	a	1-30

continued

APPENDIX 2 GERMINATION OF SEED LOTS OF 58 SPECIES WITH AND WITHOUT PRETREATMENTS.
For each collection, means followed by a different letter are significantly different for P<0.05.

Collection	Treatment	No. of Replicates and Seeds/Rep.	Germination Mean ±SD		Days to Germinate
(1981)	Stratification	4 x 100	66.25± 5.25	b	to 30
	Scarification	4 x 100	96.00± 4.24	a	1-15
	Scar./Strat.	4 x 100	93.25± 1.71	a	to 6
Hedysarum alpinum (1982)	Control	4 x 100	96.75± 2.06	a	1-29
	Stratification	4 x 100	86.75± 3.50	b	to 23
	Scarification	4 x 100	88.25± 6.75	ab	1-10
	Scar./Strat.	4 x 100	71.75± 9.74	c	
Helianthus subrhomboideus (1981)	Control	2 x 100	0.00± 0.00	a	----
	Stratification	2 x 100	53.50± 7.78	b	1-23
Heterotheca villosa (1980)	Control	4 x 25	23.75± 0.96	a	1-16
	Stratification	4 x 25	25.00± 0.00	b	to 8
Heterotheca villosa (1981)	Control	4 x 100	88.00± 4.08	a	1-29
	Stratification	4 x 100	98.50± 3.00	b	to 6
Heterotheca villosa (1982)	Control	4 x 100	96.25± 2.50	a	1-16
	Stratification	4 x 100	92.25± 6.85	a	to 7
Heuchera richardsonii (1980)	Control	4 x 25	8.25± 4.57	a	7-29
	Stratification	4 x 25	0.75± 0.96	b	7-14
Heuchera richardsonii (1981)	Control	4 x 100	57.00± 2.94	a	6-30
	Stratification	4 x 100	3.25± 3.20	b	3-14
Heuchera richardsonii (1982)	Control	4 x 100	89.75± 4.57	a	6-29
	Stratification	4 x 100	25.25± 5.80	b	to 22
Hymenoxys richardsonii (1980)	Control	4 x 25	22.50± 1.29		1-10
Hymenoxys richardsonii (1981)	Control	4 x 100	78.75± 9.22	a	2-7
	Stratification	4 x 100	95.25± 6.60	b	to 6

continued

APPENDIX 2 GERMINATION OF SEED LOTS OF 58 SPECIES WITH AND WITHOUT PRETREATMENTS.
For each collection, means followed by a different letter are significantly different for P<0.05.

Collection	Treatment	No. of Replicates and Seeds/Rep.	Germination Mean ±SD		Days to Germinate
Hymenoxys richardsonii (1982)	Control	4 × 100	67.30±16.80	a	2-21
	Stratification	4 × 100	86.00± 7.70	a	to 9
Liatris punctata (1980)	Control	4 × 25	24.75± 0.50	a	2-7
	Stratification	4 × 25	24.75± 0.50	a	to 2
Liatris punctata (1981)	Control	4 × 100	96.25± 0.50	a	2-8
	Stratification	4 × 100	98.00± 4.00	a	1-18
Liatris punctata (1982)	Control	4 × 100	76.50± 3.00	a	2-9
	Stratification	4 × 100	98.50± 1.29	b	to 6
Linum lewisii (1980)	Control	4 × 25	21.00± 2.83	a	2-26
	Stratification	4 × 25	24.00± 0.82	a	to 2
Linum lewisii (1981)	Control	4 × 100	71.25±11.59	a	4-30
	Stratification	4 × 100	81.25± 5.56	a	to 15
Linum lewisii (1982)	Control	4 × 100	89.25± 5.25	a	3-30
	Stratification	4 × 100	92.25± 1.71	a	to 6
Lithospermum ruderale (1980)	Control	4 × 25	0.00± 0.00	a	----
	Stratification	4 × 25	7.75± 2.50	b	to 22
	Embryo removed	4 × 25	3.50± 2.38	c	5-28
	Hot Water	2 × 25	0.00± 0.00	a	----
Lithospermum ruderale (1981)	Control	2 × 100	0.00± 0.00	a	----
	Stratification	2 × 100	1.50± 0.71	a	3-11
Lithospermum ruderale (1982)	Control	4 × 100	0.00± 0.00	a	----
	Strat. 2mo	4 × 100	4.25± 4.03	b	to 1
	Strat. 3mo	4 × 100	0.25± 0.50	a	
	Hot Water	4 × 100	0.00± 0.00	a	----
Lupinus argenteus. (1980)	Control	4 × 25	13.50± 2.65	a	1-27
	Scarification	4 × 25	8.50± 1.73	b	1-6

continued

APPENDIX 2 GERMINATION OF SEED LOTS OF 58 SPECIES WITH AND WITHOUT PRETREATMENTS.
For each collection, means followed by a different letter are significantly different for P<0.05.

Collection	Treatment	No. of Replicates and Seeds/Rep.	Germination Mean ±SD		Days to Germinate
	Hot Water	4 × 25	2.50± 2.38	c	1-13
Madia glomerata (1980)	Control	4 × 25	9.25± 3.30	a	3-27
	Stratification	4 × 25	17.00± 1.15	b	to 4
Monarda fistulosa var.*menthaefolia* (1980)	Control	4 × 25	19.50± 2.38	a	3-9
	Stratification	4 × 25	23.75± 1.26	b	to 6
Monarda fistulosa var.*menthaefolia* (1981)	Control	4 × 100	83.00±10.13	a	3-22
	Stratification	4 × 100	77.75± 8.73	a	1-22
Musineon divaricatum (1980)	Control	4 × 25	0.00± 0.00	a	----
	Stratification	4 × 25	1.75± 0.96	b	16-30
Musineon divaricatum (1981)	Control	4 × 100	1.25± 1.26	a	4-16
	Stratification	4 × 100	1.25± 1.26	a	1-12
Musineon divaricatum (1981)'	Control	4 × 100	0.25± 0.50	a	3
	Strat. 2mo	4 × 100	2.00± 0.00	a	1-21
	Strat. 3mo	4 × 100	5.25± 2.22	b	to 8
Oenothera biennis (1980)	Control	4 × 25	0.25± 0.50	a	5
	Stratification	4 × 25	7.50± 5.32	b	2-5
Oenothera biennis (1981)	Control	4 × 100	18.25± 5.32	a	3-26
	Stratification	4 × 100	79.50± 5.07	b	1-12
Oenothera biennis (1982)	Control	4 × 100	42.75± 2.36	a	4-30
	Stratification	4 × 100	91.50± 4.51	b	to 14
Opuntia polyacantha (1980)	Control	4 × 25	0.00± 0.00	a	----
	Stratification	4 × 25	1.50± 1.29	b	10-30
	Scarification	4 × 25	0.25± 0.50	ab	25
	Hot Water	4 × 25	0.00± 0.00	a	----
Opuntia polyacantha	Control	4 × 100	0.00± 0.00	a	----

continued

APPENDIX 2 GERMINATION OF SEED LOTS OF 58 SPECIES WITH AND WITHOUT PRETREATMENTS.
For each collection, means followed by a different letter are significantly different for P<0.05.

Collection	Treatment	No. of Replicates and Seeds/Rep.	Germination Mean ±SD		Days to Germinate
(1981)					
	Strat. 2mo	4 × 100	0.50± 0.58	a	8-12
	Scarification	4 × 100	0.75± 0.50	a	2-29
	Scar. (HCl)	4 × 100	2.00± 2.45	a	1-29
	Scar. (H_2SO_4)	4 × 100	0.00± 0.00	a	----
Opuntia polyacantha (1982)	Control	4 × 100	1.50± 0.58	a	15-21
	Strat. 2mo	4 × 100	38.25±10.44	b	5-29
	Strat. 3mo	4 × 100	35.75±10.24	b	3-24
	Hot Water	4 × 100	0.00± 0.00	a	----
Opuntia polyacantha (1981)	Control	4 × 100	0.25± 0.50	a	12
	Strat. 2mo	4 × 100	6.50± 2.89	a	9-27
	Strat. 3mo	4 × 100	6.50± 6.81	a	7-16
Oxytropis monticola (1980)	Control	4 × 25	4.75± 0.96	a	1-28
	Scarification	4 × 25	20.50± 3.22	b	1-28
	Hot Water	4 × 25	10.00± 1.63	c	1-30
Oxytropis monticola (1981)	Control	4 × 100	4.00± 2.00	a	1-16
	Stratification	4 × 100	43.25± 5.38	b	to 27
	Scarification	4 × 100	98.00± 1.83	c	1-17
	Scar./ Strat.	4 × 100	91.00± 8.12	c	to 29
Oxytropis monticola (1982)	Control	4 × 100	11.75± 6.24	a	1-19
	Stratification	4 × 100	6.50± 0.58	a	to 24
	Scarification	4 × 100	97.75± 1.89	b	1-18
	Scar./ Strat.	4 × 100	90.50± 7.23	b	to 1
Oxytropis sericea var. *spicata* (1981)	Control	4 × 100	14.00± 3.46	a	1-29
	Stratification	4 × 100	33.00± 6.58	b	to 27
	Scarification	4 × 100	92.75± 4.27	c	1-22
	Scar./ Strat.	4 × 100	83.50± 7.94	d	to 23
Oxytropis sericea var. *spicata* (1982)	Control	4 × 100	16.75± 5.91	a	1-28
	Stratification	4 × 100	11.75± 4.43	a	to 27
	Scarification	4 × 100	93.75± 3.86	b	1-8

continued

APPENDIX 2 GERMINATION OF SEED LOTS OF 58 SPECIES WITH AND WITHOUT PRETREATMENTS.
For each collection, means followed by a different letter are significantly different for P<0.05.

Collection	Treatment	No. of Replicates and Seeds/Rep.	Germination Mean ±SD		Days to Germinate
	Scar./ Strat.	4 x 100	85.00± 4.69	c	to 1
Penstemon nitidus (1980)	Control	4 x 25	1.75± 2.36	a	25-27
	Stratification	4 x 25	0.00± 0.00	a	----
Penstemon nitidus (1981)	Control	4 x 100	1.00± 1.15	a	7-29
	Stratification	4 x 100	14.50± 5.51	b	to 6
Penstemon nitidus (1982)	Control	4 x 100	2.25± 0.96	a	6-27
	Strat. 2mo	4 x 100	19.25± 3.30	b	to 10
	Strat. 3mo	4 x 100	56.00± 5.72	c	to 6
	Hot Water	4 x 100	0.50± 1.00	a	1
Penstemon nitidus (1981)'	Control	4 x 100	1.25± 1.26	a	8-30
	Strat. 2mo	4 x 100	21.25± 3.00	b	to 8
	Strat. 3mo	4 x 100	44.50±13.48	c	to 21
Penstemon procerus (1980)	Control	4 x 25	8.00± 4.24	a	4-29
	Stratification	4 x 25	11.25± 4.11	a	2-11
Penstemon procerus (1981)	Control	4 x 100	5.50± 1.29	a	8-28
	Stratification	4 x 100	62.75± 8.77	b	2-26
Penstemon procerus (1982)	Control	4 x 100	7.00± 1.63	a	6-28
	Stratification	4 x 100	14.75± 4.27	b	2-14
Petalostemon candidum (1980)	Control	4 x 25	18.00± 2.94	a	1-26
	Scarification	4 x 25	24.00± 1.41	b	1-8
	Hot Water	4 x 25	18.50± 4.20	a	1-17
Petalostemon purpureum (1981)	Control	4 x 100	50.00± 3.92	a	1-30
	Stratification	4 x 100	49.25± 5.50	a	to 28
	Scarification	4 x 100	96.25± 0.96	b	1-10
	Scar./ Strat.	4 x 100	57.00±18.67	a	to 14
Plantago patagonica var. *patagonica*	Control	4 x 25	14.50± 3.32	a	2-13

continued

APPENDIX 2 GERMINATION OF SEED LOTS OF 58 SPECIES WITH AND WITHOUT PRETREATMENTS.
For each collection, means followed by a different letter are significantly different for P<0.05.

Collection	Treatment	No. of Replicates and Seeds/Rep.	Germination Mean ±SD		Days to Germinate
(1980)	Stratification	4 x 25	6.50± 0.58	b	to 28
Ratibida columnifera	Control	4 x 25	4.25± 1.89	a	3-20
(1980)	Stratification	4 x 25	9.50± 3.32	b	1-3
Senecio canus	Control	2 x 100	82.50± 4.95	a	3-30
(1981)	Stratification	2 x 100	72.00± 4.24	a	to 30
Sisyrinchium montanum	Control	4 x 100	0.00± 0.00	a	----
(1981)	Stratification	4 x 100	0.00± 0.00	a	----
Smilacina stellata	Control	4 x 25	21.50± 0.58		18-30
(1980)					
Smilacina stellata	Control	4 x 100	59.50± 9.19	a	6-30
(1981)	Stratification	2 x 100	82.00± 9.90	b	16-30
Smilacina stellata	Control	2 x 100	0.00± 0.00	a	----
(1982)	Stratification	2 x 100	12.00± 2.83	b	29-30
Solidago rigida	Control	4 x 25	20.75± 1.50	a	3-30
(1980)	Stratification	4 x 25	22.00± 2.71	a	2-9
Solidago rigida	Control	4 x 100	33.50± 9.40	a	4-29
(1981)	Stratification	4 x 100	71.25± 5.32	b	to 14
Thermopsis rhombifolia	Control	4 x 25	2.25± 0.50	a	3-30
(1980)	Scarification	4 x 25	19.25± 2.06	b	4-30
	Hot Water	4 x 25	3.25± 2.50	a	9-29
Thermopsis rhombifolia	Control	4 x 100	4.80± 3.10	a	5-29
(1981)	Stratification	4 x 100	13.80± 6.70	a	to 7
	Scarification	4 x 100	45.30±16.80	b	1-30
	Scar./ Strat.	4 x 100	53.30±25.90	b	to 19
Thermopsis rhombifolia	Control	4 x 100	4.00± 2.71	a	5-24

continued

APPENDIX 2 GERMINATION OF SEED LOTS OF 58 SPECIES WITH AND WITHOUT PRETREATMENTS.
For each collection, means followed by a different letter are significantly different for P<0.05.

Collection	Treatment	No. of Replicates and Seeds/Rep.	Germination Mean ±SD		Days to Germinate
(1982)	Stratification	4 x 100	11.25± 4.43	b	to 30
	Scarification	4 x 100	56.75± 1.50	c	4-30
	Scar./ Strat.	4 x 100	67.25± 3.50	d	to 6
Viola adunca (1980)	Control	2 x 25	0.50± 0.71	a	30
	Stratification	2 x 25	18.50± 2.12	b	to 14
Yucca glauca (1981)	Control	4 x 100	83.75± 6.55	a	4-30
	Stratification	4 x 100	88.75± 5.25	a	2-28
Zizia aptera (1980)	Control	4 x 25	0.50± 0.58	a	1-2
	Stratification	4 x 25	3.00± 1.83	b	10-16
Zizia aptera (1981)	Control	4 x 100	0.00± 0.00	a	----
	Stratification	4 x 100	2.00± 1.83	a	to 12
Zizia aptera (1982)	Control	4 x 100	0.00± 0.00	a	----
	Strat. 2mo	4 x 100	0.25± 0.50	a	17
	Strat. 3mo	4 x 100	0.50± 1.00	a	4-10
	Hot Water	4 x 100	0.00± 0.00	a	----
Zizia aptera (1981)	Control	4 x 100	0.00± 0.00	a	-----
	Strat. 2mo	4 x 100	9.50± 1.91	b	4-14
	Strat. 3mo	4 x 100	10.50± 4.65	b	2-15

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[1] all germinated in the pretreatment
[2] tested in 1983 (two years after collection)
[3] collected at Elkwater Lake
[4] collected at Milk River Ridge Reservoir