LOW TEMPERATURE SEED STORAGE FOR WESTERN CONIFERS 1/

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If all forest tree species produced good seed crops every year, we would have no long-time seed storage problems. Unfortunately, most of the coniferous species commonly used in reforestation bear good seed crops only at intervals of several years. For example, the more important western conifers can be depended on for good seed crops only every 3 to 7 years (Table 1). To conduct regular reforestation programs on a large scale, therefore, we have the alternatives of nursery production fluctuating with annual seed production or collecting enough seed in the good years to supply the necessary stock for 2 to 6 years' production. Administratively the latter is preferable; so these extra quantities of seed must be stored in such a manner that the maximum viability is retained.

Conditions Required for Long-Time Seed Storage

As coniferous tree seeds ripen, they undergo certain characteristic physical and chemical changes. Physically they usually change in color and lose moisture. Chemical composition usually is altered as follows: "Soluble organic compounds such as simple sugars, fatty acids, and amino acids are gradually converted into more complex carbohydrates, fats and oils, and proteins" (5). In the course of germination, the biochemical changes usually are the reverse of those occurring during seed ripening. These changes cannot take place unless the seed has access to moisture, favorable temperatures, and sufficient oxygen. Here is the key to successful storage practices. The conditions required for germination must be withheld from the seed which, at the same time, must not be injured.

Seeds of some trees, particularly the nut species, must be kept moist or they lose their viability. Others, which have hard, impermeable seed coats, such as many of the legumes, may be kept for many years without special precautions. Seed of the majority of our tree species, however - and this includes most of the conifers - retain their viability best under dry, cold storage.

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2/ Maintained by the U.S. Department of Agriculture, Forest Service, in cooperation with the University of Minnesota, University Farm, St. Paul 1, Minnesota.

Table 1.-- Seed Crop Intervals for Some Western Conifers

Species	Seed-year frequency	
	Good Crops : Years	Light Crops : Years
Alaska-cedar (Chamaecyparis nootkatensis)	Occasional	Most intervening
Port-Orford-cedar (C. lawsoniana)	4-5	do
Western redcedar (Thuja plicata)	2-3+	Intervening
Douglas-fir (Pseudotsuga taxifolia)	3-7	do
California red fir (Abies magnifica)	2-3	do
Grand fir (A. grandis)	2-3	do
Noble fir (A. procera)	Infrequent	do
Pacific silver fir (A. amabilis)	2-3	do
White fir (A. concolor)	2-4	do
Western hemlock (Tsuga heterophylla)	2-5	do
Western larch (Larix occidentalis)	5-6	Most intervening
Jeffrey pine (Pinus jeffreyi)	2-4	1-3
Lodgepole pine (P. contorta var. latifolia)	1-3	Intervening
Ponderosa pine (P. ponderosa)	2-5	2-3
Sugar pine (P. lambertiana)	3-5	Most intervening
Western white pine (P. monticola)	4-6	3
Redwood (Sequoia sempervirens)	1+	Intervening
Engelmann spruce (Picea engelmanni)	2-3	do
Sitka spruce (P. sitchensis)	3-4	do

Methods of Cold Storage

Moisture Content

Before storage seeds of most American conifers should be dried down to a moisture content of 10 percent or less of oven-dry weight. Kiln-dried seeds or those which have been air-dried in dry climates, as in the Rocky Mountain region, ordinarily have a moisture content low enough for storage. Any additional drying needed should be rapid enough to prevent heating or molding, yet not so rapid or at such high temperatures as to injure the seeds.

The seeds must not only be put into storage at low moisture contents, but they must be prevented from regaining moisture in storage. This requires either that the seeds be held in sealed containers or that the entire storage chamber be kept at suitably low relative humidities. Normally it is more practical to use sealed containers.

Temperature

Experimental evidence has shown that temperatures just above freezing slow down the life processes within the seed and yet maintain its viability. Temperatures between 33° and 50° F. have been found satisfactory for many species. As a rule, constant temperatures have proved better than those which fluctuate more than a few degrees. Seeds of many species can be stored satisfactorily for a few years in cool cellars or special insulated storage sheds in which temperatures show a gradual rise and decline with the seasons, but viability is retained longer and more fully in controlled cold storage.

Oxygen

Pine seeds (loblolly, longleaf, slash, and red) stored in a partial vacuum kept better than those in ordinary sealed containers at room temperatures, but there was little difference when storage was at low temperatures (1). Normally it is easier to provide low temperatures than partial vacuums for storing large amounts of seed.

Containers

The type of seed cans with screw-tops used by the U.S. Forest Service in several regions has proved quite suitable for storing seeds for several years, so long as storage conditions were otherwise favorable. Small lots can be kept in jars or similar containers sealed with paraffin.

Storage of Some Western Conifer Seeds

Results of cold storage have been published for only some 10 of the more important western conifers (Table 2). Information is also available for 9 less important pines (whitebark, bristlecone, knobcone, foxtail, shore, Monterey, Santa Cruz Island, and Torrey pines) (2). This information is quite consistent in indicating that viability of these western conifer seeds can be maintained with little or no loss for 5 to 10 years if the seeds are held in sealed storage at temperatures of about 40° F.

Douglas-fir seed has retained full viability for at least 4 years when stored at 40° F. in sealed containers. It seems reasonable that seed of this species could be held at least 3 more years without serious deterioration. Supplies could, therefore, be stored satisfactorily over the maximum period to be expected between good seed crops.

Seed of the true firs can be held little more than one year under ordinary storage. However, seed of grand fir still retained 50 percent of its initial viability after 11 years' sealed storage at 40° F. and seed of noble fir had lost very little germinability after 5 years' storage at 36-39° F. White fir seed apparently is more perishable; samples have deteriorated after 4 years' sealed, cold storage. There seems to be no good reason why seed of California red fir, Pacific silver fir, and other western true firs could not be stored satisfactorily in the same manner for the 3 to 4 years which may elapse between good seed crops.

The more important western pines all produce good seed crops at intervals not exceeding 6 years. Studies show that seed of all these species can be kept at 40° F. for several years with little or no impairment of viability. Jeffrey pine and western white pine seed have been stored for over 8 years, lodgepole pine for over 9 years, 3/ and ponderosa pine for over 11 years with full viability. After 11½ years' storage at 40° F., sugar pine seed retained 40 percent of its initial viability; some germination was still obtained after 14½ years' cold storage (2). As a matter of fact, seed of Pinus ponderosa var. scopulorum was still viable after 23 years' storage in a cool cellar in a dry climate.

3/ There may be little need to store this seed because of the supply normally present in serotinous cones.

Table 2.-- Some Results with Cold Storage of Western Conifer Seeds

Species	Temperature	Duration	Viability reduction	Data source
	Degrees F.	Years	Percent	
Douglas-fir	40	4+	0	(5)
Grand fir	40	11	50	(5)
Noble fir	36-39	5+	Little	(5)
Jeffrey pine	40	8+	0	(2), (5)
Lodgepole pine	40	9+	Little	(2), (5)
Ponderosa pine	40	11+	0	(2), (5)
	5 to 23	4+	0	(1)
Sugar pine	40	11+	60	(2), (5)
Western white pine	40	8+	0	(2)
Redwood	26-30	1-10	50+	(5)
Engelmann spruce	40-60	5	20	(5)

Redwood seed has been stored up to 10 years at 26° to 30° F. with a loss of about 50 percent of its initial viability. Because of frequent good seed crops, there is little need ordinarily for storing redwood seed more than one year. Seed of the related giant sequoia apparently keeps better. Reports are that its seed has kept for 8 to 24 years with a moderate loss in viability.

Engelmann spruce seed stored in sealed containers in a cool cellar (temperature range probably about 40° to 70° F.) retained its viability unimpaired for 3 years and had lost only about 20 percent of it in 5 years (5). In view of this and the fact that seed of white and red spruces have kept well for at least 10 years at temperatures near 40° F., it seems probable that Engelmann, Sitka, and other western spruce seeds can be held satisfactorily in cold sealed storage for at least 5 to 10 years, which usually is all that is necessary.

Some Species for which Information Is Lacking

There are several other important western conifers for which information on cold storage of seed is lacking. For several of them, however, we can make some assumptions based on storage behavior of seed of related species.

Storage information is lacking for seed of Port-Orford-cedar and Alaska-cedar, but seed of the closely related southern white-cedar has kept well for one year when stored naturally in the peaty forest floor. Seeds of some species in the closely related genus Cupressus have retained considerable viability for 10 years when stored unsealed at temperatures fluctuating from 40° to 90° F. (5). It is

reasonable to expect, then, that Chamaecyparis seeds can be held for several years in sealed storage at about 40° F. with good retention of viability.

Western redcedar seed maintained fair viability for 2 years when stored in sealed containers at ordinary room temperatures. However, seed of northern white-cedar (in the same genus) kept well for 5 years in air-tight containers at 35° to 40° F., although the seed deteriorates rapidly at higher temperatures or when exposed to moisture (5). Western redcedar seed should keep well for at least 3 to 5 years in air-tight containers stored at temperatures between freezing and 40° F.

Western hemlock seed stored at room temperature for 2 or 3 years in sealed containers lost little germinative capacity. One lot of eastern hemlock seed germinated well after 4 years' storage at 41° F. in sealed containers but had deteriorated after 6 years' storage (5). Presumably western hemlock seed could be stored satisfactorily at slightly above freezing temperatures for the 5 years which might occur between good crops.

Western larch seed has been kept for 1 or 2 years in sealed containers at room temperatures with an annual loss of about 6 percent of its germinative capacity (5). European larch seed lost no viability in 4 years' sealed storage at 32° to 50° F. (5). There should be a good possibility, therefore, that western larch seed could be held satisfactorily in sealed storage at about 40° F. for the 5 or 6 years which might be required between good crops.

Some Practical Considerations

Evidence is consistent that seeds of several western conifers can be stored satisfactorily for 5 or more years at low moisture contents in sealed containers at temperatures near 40° F. On large operations involving seeds of species which produce good seed crops not oftener than 3 years it may pay to install cold storage facilities.

In some localities commercial cold storage facilities are available. Such establishments usually maintain temperatures below the 40° F. found satisfactory for many tree seeds. In fact, temperatures usually are held below freezing. It is important to know, therefore, whether tree seeds can be stored safely at sub-freezing temperatures.

Fortunately there are tests on seed of a few coniferous species which were stored at temperatures between 5° and 23° F. These tests indicate that seed of ponderosa, red, loblolly, longleaf, slash, and shortleaf pines and white and Norway spruces kept well for 4 to 7 years at sub-freezing temperatures (1). These seeds were stored at moisture contents between 0 and 6 percent, many of them at less than 1 percent. If the seeds are sufficiently dry, they apparently can withstand sub-freezing temperatures for several years without injury. Possibilities seem good, then, that many commercial cold storage facilities can be used to advantage in storing conifer seeds.

It should be stressed that conifer seeds scheduled for prolonged cold storage should contain less than 7 percent moisture. Tests at the Lake States Forest Experiment Station with red pine and eastern white pine have demonstrated this (3, 4). With both species lower moisture contents have proven better.

Usually conifer seeds which are extracted in forced-air kilns and often in convection kilns have moisture contents low enough for long storage. It is desirable also that the moisture content of the seed be kept low throughout the storage period. Even in sealed jars there may be a build-up of moisture, as shown in the eastern white pine tests, supposedly from leakage around deteriorating rubber rings. For example, seed with an initial moisture content of 5.6 percent 10 years later contained 11.2 percent moisture (4).

More Knowledge Needed

This brief summary of knowledge on the cold storage of western conifer seeds points out not only some promising leads but also a conspicuous lack of knowledge for many species. Some information is available on the effects of cold storage of seed for only about half of the more important western conifers. Many of these need more study to clarify the most desirable moisture contents and temperatures for long-time storage. Comprehensive seed storage studies are needed also for those species not yet investigated. Only for ponderosa pine is there information on the effects of seed storage below freezing temperatures. This should be studied further for all the important species.

Summary

Most western conifers bear good seed crops only every 3 to 7 years. For regular, large-scale reforestation projects it is necessary, therefore, that seeds of most species be stored for 2 to 6 years. Information indicates that seed of the following 10 species can be kept at about 40° F. in sealed containers for 5 to 10 years with little loss in viability: Douglas-fir, grand fir, noble fir, Jeffrey pine, lodgepole pine, ponderosa pine, sugar pine, western white pine, redwood, Engelmann spruce, and 9 less important pines. White fir seed can be held for 3 or 4 years. Seeds of several other important western conifers probably can be stored in the same manner because of their similarity to other species for which information is known. These include: Alaska-cedar, Port-Orford-cedar, western redcedar, California red fir, Pacific silver fir, western hemlock, western larch, giant sequoia, and Sitka spruce.

Many commercial cold storage plants are run at temperatures below freezing. Studies have shown that seed of ponderosa pine and some other pines and spruces can be stored safely at such temperatures for several years at low moisture contents. Probably other species can also be stored in the same manner.

It is important that seed contain less than 7 percent moisture when placed in long-time storage. The containers should be sealed so that the moisture content cannot increase over the storage period.

Research has given promising leads as to the requirements for long-time seed storage for several species. However, more information is needed for many of these species, and those species not yet studied should be the subjects of research. There is need to investigate especially the effects of sub-freezing temperatures on the viability of seeds of all important species.

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Mr. Rindt: Now I have hurried through that because there is a lot of stuff in there I think we are pretty much familiar with. The thing that struck me throughout the paper was his continual reference to 40° Fahrenheit. We have felt that we needed much colder storage than 40° and maybe we are wrong. I think that is something that we should know about, because the cost of storage certainly increases as we have to go to the lower temperatures.

Mr. Salisbury: I think that if you have it dry enough, you don't need it so cold to keep the seed from deterioration. He is recommending 7% or less moisture content, and if the seed is quite dry, you don't need it so cold to keep it from deteriorating.

Mr. Rindt: Well, yes and no. I think this, that if seed is higher than 7% or 10% moisture, and you subject it to the sub-freezing temperatures, it is likely to be damaged, but also that seed at high moisture content would deteriorate at other temperatures too. I think the key to storage, as he pointed out, is that seed requires certain conditions to germinate, and as those conditions cease to exist the seed loses its germinating capacity. It has to have heat; it has to have moisture; it has to have oxygen. Now, if you take away any one of those things, you are going to slow down the processes that go on within the seed. I think that if we could draw a complete vacuum on seed that we could keep it successfully for a number of years, or if we would have it absolutely dry, of course, it would probably kill it, so we have to have some moisture.

Mr. Salisbury: I was wondering about that figure of zero to one percent that he mentioned for one kind of seed in there. It sounded very dry to me.

Mr. Rindt: Very dry.

Mr. Cameron: We have, of course, stored considerable seed, and acting on the advice of a good many people, we have stored a lot of our seed at zero F., in sealed containers, at moisture contents between 5% and 8%. This was primarily a guess on our part, but a result of considerable experience on other people's part; but in order to verify it, the Boyce Thompson Institute is conducting an experiment for us on the storage of seed, which to date is of too short duration. It is going into its third year now, but the indications are that the zero temperatures are very definitely better than the 35° to 40°.

Mr. Rindt: That is what we have found. Now, Rudolf talks about small losses in germination or germinating capacity. Well, we can't afford even those small losses. If we are paying anywhere from five to ten or fifteen dollars a pound, as we will have to for some species such as hemlock and some of the spruces perhaps, even 5% amounts to quite a bit, and it pays us to put a little more investment in proper storage to maintain as close to the original germination as we possibly can. A 50% loss, which he talks about, is way too high for some of the species as far as storage is concerned. He makes another statement which is all right for tests, but as far as practical storage is concerned doesn't work, and that is a safe supply between seed crops. Well, we have to have more than a safe supply between seed crops, because maybe we are going to get a fire and we need three or four thousand pounds of seed right now, so we would like to be able to store seed for a long time, regardless of these seed crops. We take advantage of them to build up our supply, but we might have to carry some seed beyond them just because of conditions.

Chairman Webster: I think your point is very well taken, Charlie, in view of the fact that we are making fairly rapid strides in direct seeding now. It is going to take a vast quantity of seed if we get all the factors worked out successfully in direct seeding. It is going to take vast quantities of seed from now on, and I believe we are working in the right direction.

Mr. Corson: We have stored Ponderosa pine and Jeffrey pine only in sealed cans at 40° and kept it for 10 years without any serious loss in germination. That is not in a cold storage. It was in a cellar where we maintained a temperature of around 40°. I don't know what the moisture content was. It was just regular air-dried seed.

Mr. Rindt: There seems to be evidence, and good evidence, that certain species of seed will store successfully at 40° or between 32 and 40, in that range, especially if they are in sealed containers, and maybe we need some work along the line of different species and maybe we only need the sub-freezing for certain species.

Mr. Lanquist: Well, I believe in seed storage that temperatures are very important all right, but I believe that moisture conditions in the seed are just as important. Rudolf said that you should try to maintain the moisture content of 7% to 8%. Well, that will be very hard to do, because as he said, the air will come into the broken seeds, and he didn't mention how to prevent it. We had some trouble with seed that collected moisture. We bought some silica gel and put it in our drums where we stored the seed and that took care of the moisture

Mr. Lanquist (cont'd): content very well. We weighed the seed when we put it in, and I think it was about 8%. Then we weighed it again and had it going up to about 12%. Then we put the silica gel in there and kept it there for I believe about 4 months and it picked up the moisture, so the moisture content was about 7 or 8, just about where we started, so that is a pretty good deal if anybody has trouble. We did have trouble; moisture did collect in the bottom one-third of the drums, but the silica gel took care of it.

Chairman Webster: Do you weigh out a portion of silica gel per portion of seed, or how do you approach the correct amount to put in?

Mr. Lanquist: Well, I just took a shot in the dark, to tell you the truth, and I took a five-pound bag of silica gel to a 50-pound drum of seed. The drum wasn't quite full. It was probably about a foot from the top of being full, and we put the silica gel on the top.

Chairman Webster: Well now, do you feel if you put that silica gel in the seed the original time you put the seed in the drum would it maintain your moisture control and hold it at the 7 to 8%?

Mr. Lanquist: Well, I couldn't say that because, as I said, we only tried it for 4 months, but I believe a fellow could go in and sample his seeds. I think you should do that no matter what, if you have a big supply of seed, and you have a lot of money invested in your seed. You certainly should go and check on your seed, because there will be a big surprise if you are ready to sow and your seed has deteriorated in storage. You might go in and take some samples, probably 3 or 4 times a year.

Mr. Rindt: Terrific job.

Mr. Lanquist: Well, it would be a job, but it might pay off.

Mr. Rindt: Well, we have to get a method of storage that we are going to know enough about so we don't have to do a lot of that work, because we are talking about thousands of pounds of seed, and it is just a big job to go in and make adequate samples periodically. We should do some of it, of course, but we can't do a lot of it.

Mr. Isaac: I have a little additional information that Rudolf didn't have access to. Charlie and I have been working with the Boyce Thompson Institute on a series of tests. The first ones are now 5 years old, and I sent all our northwest species. At that time Dr. Barton only had facilities for storage at a minus 5° Centigrade, which would be about 21° Fahrenheit, wouldn't it? I will just read off what the 5 years results are for the various species:

COLD STORAGE TESTS MADE BY DR. LELA V. BARTON
OF BOYCE THOMPSON INSTITUTE FOR PLANT RESEARCH
for
PACIFIC NORTHWEST FOREST EXPERIMENT STATION

Record of five-year storage in open and sealed containers at + 5° C. and -4° C.

	Germ. Test at 20° C. Stored at				Germ. Test in Greenhouse Stored at			
	+ 5° C.		-4° C.		+5° C.		-4° C.	
Species	Open	Sealed	Open	Sealed	Open	Sealed	Open	Sealed
Sitka spruce	54	0	40	50	45	0	51	46
W. red cedar	0	0	0	12	0	0	0	2
P. O. cedar	24	16	23	35	22	10	12	10
W. hemlock	94	0	63	83	15	0	29	7
Douglas-fir	30	12	16	30	76	12	45	77
Ponderosa pine	37	35	35	44	30	42	44	52
Silver fir	10	9	4	10	20	4	11	16
Noble fir	7	14	1	14	14	20	4	14

Mr. McDaniel: The thing I have always been interested in is, our seed room is zero, maintained at zero all of the time. We have enough room for around five and a half tons of seed, which is kept in sacks, as you fellows probably saw when you were down there. I have talked it over with a lot of cold storage men, and I think it is a thing to be considered. Cold storage engineers claim that your cost is twice as much to run your cold storage room at zero than at ten above, and sometimes I wonder if we are using lower temparatures than necessary. I feel it would keep seed just as good as at zero. It costs us for this seed about $18.00 a month, and if you could cut that in half and still maintain the viability of your seed, I think it is worthwhile. I wondered if anyone has carried on tree seed storage at ten above zero rather than that zero mark?

Mr. Rindt: I would like to say something about that in just a minute. I believe that the sub-zero storage of seed originated with the Forest Service. I am not sure, but anyway, we have stored that way for quite a while. One of the reasons was that we found through some tests that seed did keep very well at sub-zero temperatures without loss of viability or without damage to the seed, so we were just playing it safe. Now we are coming to the point where, as Verne pointed out, we can save some money and should save some money by higher temperature storage, if the seed will keep equally well. There is something about the moisture that should be remembered, and that is that when seed is stored at sub-zero

Mr. Rindt: (cont'd) temperatures, the moisture remains constant, because the moisture is frozen out of the air and you don't have to worry about your airtight sealing or anything like that, but as soon as you raise that temperature above freezing, then you are going to get moisture condensation and you get into other troubles; so you are going to have to go to airtight containers. One thing leads to another.

Mr. Finnis: Has anybody got an easy and cheap way of determining moisture content?

Mr. Cameron: Yes. -- I wouldn't say it is cheap; the investment is not cheap -- a Sten light moisture tester, which measures the moisture by conductivity. You can obtain your moisture content within a matter of seconds. Initial investment is somewhere near $500 for the machine.

Mr. Salisbury: Grain storage men have been using that and they claim it is giving too high a moisture content.

Mr. Cameron: Very much depends on how your machine is graduated. We had that experience and found, after having the machine recalibrated, the results are very comparable.

Mr. Smith: I would just like to make a brief comment. A seed is a living thing, no matter how you store it, and at low temperatures, it is still alive and still undergoing respiration. You may be able to store it at a lower temperature on different species because of the characteristics of the tree, but oxygen enters into it, and you have a respiration going on because the stored food on which the germ draws is liberating carbon dioxide and water. That is where the water comes into it. The seed itself is producing water in the respiration, and for each seed there may be a critical temperature at which you will lose viability if the temperature is not sufficient to permit it to go on.

Chairman Webster: That is a very good point.
(He then introduced Mr. Forrest Deffenbacher.)

Mr. Deffenbacher: As you fellows all know, I am the fellow that has given this same subject for how many years now -- three, four -- so some of it is going to be a repetition pretty much of what we started with. How I first got into this subject, Mike says, "I would like to have a paper on cold storage of seedlings." Well, I didn't know anything about it at all, so I tried to find some information in different places and found that it was not available. I talked to Ernie Wright, who has done probably more on this subject than I have. He began to look and he couldn't find it either, so the two of us started this experiment of storage of seedlings. This was back in 1947.