Chapter 3

Seed Harvesting and Conditioning

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Contents

Introduction

Most forest trees and shrubs grown for artificial regeneration purposes, and some grown horticulturally, are reproduced from seeds. Seed quality is, therefore, of critical importance in determining the many options and outcomes in producing a crop of seedlings. Only high-quality seeds that can be planted by machinery permit bareroot seedlings to be grown at the uniform and controlled bed densities needed to produce the desired seedlings at the most economical cost. Uniform and controlled bed densities facilitate more efficient and mechanized methods of weed control, root-pruning, and lifting of seedlings. Adverse consequences occur in both labor costs and the genetic makeup of the seedlings unless high-quality seeds are used and properly managed. Therefore, a poor job of seed handling at harvest and conditioning can have serious negative impacts on the quality and availability of seedlings. However, a good job at this point will have positive impacts on seedling status. It also makes sense economically to focus effort at this point in the process, because more efficiencies can then be realized at later stages.

This chapter begins with what to consider in planning a seed harvest, how to harvest, how to temporarily store seeds, and how to extract, clean, and upgrade the finished seeds. A discussion of quality control concludes the chapter.

Harvesting

Seed harvest is the first step in producing a high-quality seedlot. This statement assumes that genetic considerations have been properly addressed in planning the seed harvest (see chapter 2). Quantities of seeds to collect, initial seed quality, and the timing of collections are the key quality factors in seed harvest. Timing is important because maximum seed viability and vigor occur at physiological maturity (figure 1). Collecting too early results in lower seed quality due to seed immaturity and reduced yield. Collecting too late can also be detrimental, because seeds may be lost to seed shed, predation by animals or insects, or seed deterioration. However, some species mature after natural seedfall; these include various ash species (*Fraxinus* spp.) and ginkgo (*Ginkgo biloba* L.). The initial seed quality must be assessed to avoid collecting seeds that are empty, malformed, or damaged. Quantity of seeds to collect influences quality because the seeds must be processed before deterioration becomes measurable.

Planning and preparation

Quantities to collect. The quantity of seeds to collect can be computed from nursery records and seed-plant production records of past harvests (table 1). If this information is not available, then general averages can be taken from the tables in the generic chapters of this handbook. Determining the number of cones or fruits needed to give this desired amount of seed can be predicted by cutting open a sample of cones or fruits. Because of variation from crop to crop, location to location, and even tree to tree, it is wise to always cut a few fruits to be sure of the quality and not waste collection effort on poor crops. Figure 2 shows a cutting method for assessing the number of filled seeds in a conifer cone; table 2 lists a good average seed count for 4 western conifers. When the desirable number of seeds per cone is found on the cut face, then collections are made. Usually a minimum number of good seeds must be found when cutting before the crop is accepted. This minimum number will vary with the need for the seeds, the cost of collection, and the quality of alternative collection sites. Douglas (1969) suggests that 50% of the seeds exposed on the cut face of true fir (*Abies* spp.) cones should be full, and Schubert and Adams (1971) set this percentage of good seeds at 75% for pines (*Pinus* spp.).

How the number of seeds on the cut face of a cone corresponds to the total number of seeds in the cone is shown in table 3. Such a table is constructed by making longitudinal cuts on the cones, counting the number of seeds on the cut face, and then opening the cone by drying or dissection to determine the total number of good seeds in the cone. For example, the authors of the data in table 3 found in their samples that when 8 good seeds appeared on the cut face of longleaf pine (*Pinus palustris* P. Mill.) cones, there would be, on the average, 59 seeds per cone. In figure 3, cutting ash seeds to determine the percentage of filled seeds is an example of a way to examine the quality of a hardwood fruit. Such cutting procedures provide an estimate of the amount of good seed that can be expected from a given quantity of fruits or cones.

Positive species identification. Another vital step is making a positive identification of the species. Sometimes this is relatively easy. For example, there may be no close relatives to the species in the area. Douglas-fir—*Pseudotsuga menziesii* (Mirbel) Franco—is the only species in its genus in the coastal western United States and has a unique cone. It thus presents little problem in species identification. Oaks (*Quercus* spp.), on the other hand, overlap in their range in many parts of the country and often hybridize, making positive identification more challenging. An addi-

Figure 1—Chapter 3, Seed Harvesting and Conditioning: seed quality changes over time.

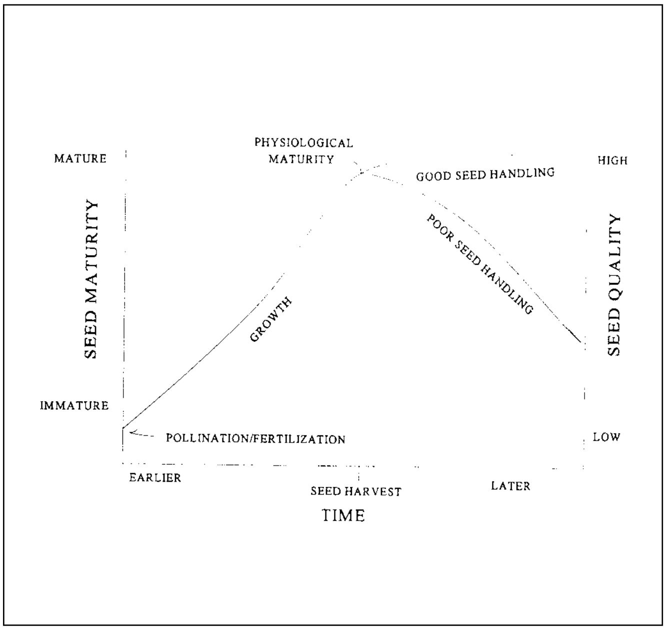


Figure 2—Chapter 3, Seed Harvesting and Conditioning: cutting a pine cone longitudinally helps estimate when and where to collect cones

Table 1—Chapter 3, Seed Harvesting and Conditioning: the questions to answer in computing the amount of seeds to collect

Question	Value	Calculated quantity of seeds needed	Example
How many plants are to be produced?	200,000	—	—
How many years of production is this?	3	200,000 x 3	600,000
What is the ratio of seedlings to viable seeds?	80%	600,000 ÷ 0.8	750,000
What is the viability of the seeds?	80%	750,000 ÷ 0.8	937,500
How many seeds are there per unit weight*?	99,000	937,500 ÷ 99,000	9.5 kg
What is the purity?	95%	9.5 ÷ 0.95	10 kg
What volume of the "raw collection unit" (that is, seeds, fruits, or cones) must be collected to obtain the desired weight* of pure seeds?	0.8 kg/hl	10 kg x 0.8 kg/hl	12.5 hl
Is there sufficient capacity for post-harvest storage & timely conditioning for the desired volume of seeds?			

* Weight in kilograms (kg) or pounds (lb).

tional challenge is presented when the scientific names are debated by taxonomists. Genera such as locust (*Robinia* L.) and blueberry (*Vaccinium* L.) have gone through extensive reclassifications. Therefore, careful attention to nomenclature and good record keeping are very important in maintaining control over regeneration work. This is especially true when many diverse species are involved. The finished seeds of many related species are impossible to identify and separate. Without good collection records, the true identity of a seedlot can easily be lost. Collecting and preserving leaf, bud, and twig samples along with a seedlot can serve as an excellent check on species identity. Collecting these vegetative parts is important for seed collectors who lack knowledge of botany. Later, knowledgeable persons can verify the identity of a seedlot from the vegetative parts.

Careful seed-source identification is also vital. Not properly documenting the source of a seedlot can be as disastrous as misidentifying the species, perhaps even more so,

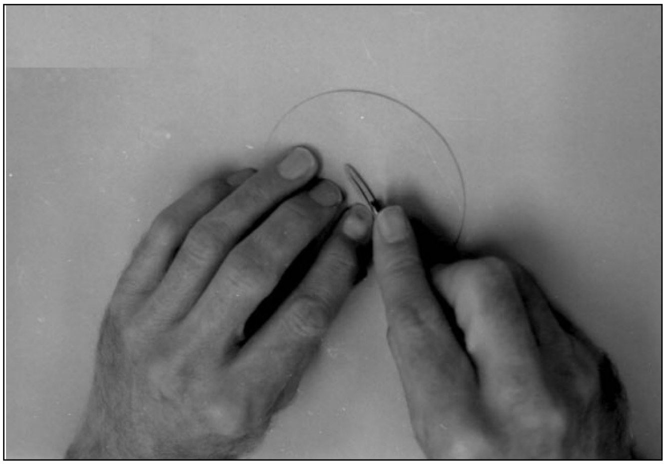


Figure 3—Chapter 3, seed Harvesting and Conditioning: cutting ash samaras open will tell if the fruits are filled and if the embryos are mature.

because the mistake might not be known until an outplanted crop fails because of poor adaptation. Seed certification procedures are a good way to track seed-source identity.

Seed structures. Accurate and complete knowledge of seed and fruit structures is essential for making accurate estimates of initial seed quality. When beginning work with an unfamiliar species, workers should dissect some fruits and seeds in order to become familiar with the normal seed structures. The condition of the embryo cannot be evaluated if its location and shape are not known. Workers also need to recognize the outside appearance of seeds. Seeds, especially small ones, can be confused with trash or other floral parts if their true shape is not known. Chapter 1 provides a general discussion of flowering and seed formation. Detailed descriptions and drawings showing the seed structure and maturity indices are presented for each genus in part 2 of this manual.

Seed maturity. Fruits and cones should be collected only when seeds are sufficiently mature. Properly timing the collection of seed depends on correctly estimating seed maturity, which is often difficult because it is influenced by weather, genotype, site quality, site aspect, and location on the plant. Seasonal events and location cause wide variability in timing and length of the collection period. For example, if snow is deep and melts late at a high-elevation site, trees may flower so late that seedcrops do not even mature. Conversely, an early spring and dry summer can cause seeds to ripen and disperse very early. When drying winds occur in the autumn, most seeds of several western conifers and eastern white pine (*Pinus strobus* L.) will disperse in a few days. Conversely, rainy conditions may result in cones retaining most of their seeds for weeks or months. A high wind or a rainstorm may rapidly disperse an entire crop of mature seeds of some shrubs. Cones generally ripen first at lower elevations and south and west slopes, later at higher elevations and north and east slopes (Schubert and Adams 1971). Maturity may be reached several weeks earlier on hilltops than in nearby bottoms (Cobb 1959). The write-ups for the individual genera in part 2 should be consulted for maturity indices. Judging maturity, however, requires experience; in lieu of experience, careful observation and experimentation are essential to properly apply maturity indices or to develop them. Fortunately, for many species, there is a week or more between seed maturity and seed shed or fruit

Table 2—Chapter 3, Seed Harvesting and Conditioning: minimum average number of good seeds on cut face of cones needed to justify collection of cones of some western conifers

Species	Seed count
Pseudotsuga menziesii (Mirb.) Franco	6
Tsuga heterophylla (Raf.) Sarg.	8
Pinus ponderosa P.&C. Lawson	10
Picea sitchensis (Bong.) Carr.	14

Table 3—Chapter 3, Seed Harvesting and Conditioning: sound seed yield per cone for 4 pine species as estimated from the number of sound seeds exposed when cones are bisected longitudinally

Sound seeds exposed	*Pinus palustris* (Louisiana)	*Pinus taeda* (Louisiana)	*Pinus elliottii* (Louisiana)	*Pinus elliottii* (Georgia-Florida)	*Pinus echinata* (Virginia)
2	23	31	20	31	12
4	35	44	35	50	22
6	47	57	50	69	31
8	59	70	65	87	41
10	71	83	80	106	51
12	83	96	95	124	60
14	95	109	110	143	70

Sources: Derr and Mann (1971).

drop. This delay provides some margin for error in estimating maturity. Prompt action is, however, necessary once maturity has been reached.

Immature fruits may be collected by mistake from species having fruits that require 2 or 3 years for development. Alaska-cedar (*Chamaecyparis nootkatensi*s (D. Don) Spach) and western juniper (*Juniperus occidentali*s Hook.) are examples of species that bear immature seed structures that are nearly equal to mature ones in color and size. Collecting intermingled mature and immature fruits should be avoided, because these fruits are difficult to separate (Stoeckeler and Slabaugh 1965). At the other extreme is the possibility of collecting empty conifer cones. Cones that have recently shed their seeds will close during rainy weather (Allen and Owens 1972), and workers must be careful not to collect these closed empty cones by mistake.

Maturity for collection is most often judged subjectively from the appearance of the cones, fruits, or seeds. Green color changes to yellow-green, yellow, brown, reddish, or purple. Fruits begin to soften. Scales or bracts begin to crack or flex. A few early-maturing individuals begin to drop their seeds. Such subjective indicators have a variety of shortcomings (Schubert and Adams 1971). The color changes may not be the same with every individual or population of plants. Weather can accelerate or modify the appearance of the indicator. On the whole, however, these indicators have proven to be reasonably practical. Their chief drawback is their dependence on the experience and judgment of collectors. When in doubt, it is generally better to shorten the collection period than to collect immature seeds that will have low viability and the tendency to produce low-vigor, deformed seedlings (Heit 1961, Schubert 1956).

Some attempts have been made to develop more-objective maturity indices. Chemical constituents have been analyzed and related to maturity for Douglas-fir and noble fir (*Abies procera* Rehd.) (Rediske 1968). This type of approach has not been widely used, mostly because of the difficulty of getting samples to a laboratory and then returning the information on a timely basis to the field.

Measuring specific gravity is used to evaluate the maturity of conifer cones. As a cone matures, it loses water and its specific gravity decreases. The flotation procedure to measure specific gravity can be done in the field by collectors. Cones placed in a liquid with the appropriate specific gravity will sink if immature and float if mature. The specific gravity values for ripe pine and fir cones are listed in tables in part 2 of this manual. Although simple in application, this version of the flotation procedure requires finding a fluid with the correct specific gravity and carrying supplies of it into the woods. Many of these fluids are potentially polluting substances such as ethanol, kerosene, motor oil, or linseed oil and they and the tested cones, which have become contaminated, must be carried out of the woods. Thus, this version of the flotation method is rarely used today.

Instead, specific gravity values of cones can be calculated from values obtained by using water in a graduated metric cylinder with increments marked at 1-ml intervals. The cylinder should be the smallest size that the cone will fit into and made of lightweight plastic. Water obtained in the field can be used, thus minimizing the amount of material to transport.

Specific gravity estimates must be made immediately after the cone is removed from the tree. A few minutes delay, even in a moisture-proof container, will allow the cone to dry slightly, causing the specific gravity to be estimate below (lower s.g.) than it actually was on the tree.

Early collection, that is, before natural maturity date, is possible with the following species:

- sweetgum *(Liquidamber styraciflua L.)* (Bonner 1970a; Wilcox 1966)
- loblolly pine (*Pinus taeda L.*) (Cobb and others 1984; Waldrip 1970)
- Douglas-fir (*Pseudotsuga* menziesii (Mirbel) Franco) (Silen 1958)
- eastern white pine (*Pinus strobus* L.) (Bonner 1986)
- grand fir (*Abies grandis* Dougl. ex D. Don Lindl.) (Pfister 1966)
- white spruce (*Picea glauca* (Moench) Vozz) (Winston and Haddon 1981)
- red pine (*Pinus resinosa* Ait) (Winston and Haddon 1981)
- blue spruce (*Picea pungens* Engelm.) (Fechner 1974)

For these species, the cone or fruit is dried in a strictly controlled manner to allow for proper maturation of seeds, fruits, or cones. Those who wish to attempt to collect cones or fruits early and after-ripen them should consult the literature and do some test runs of the procedure. For further references on after-ripening and other seed maturation topics, check the review by Edwards (1980) on maturity and quality of tree seeds.

FLOTATION PROCEDURE

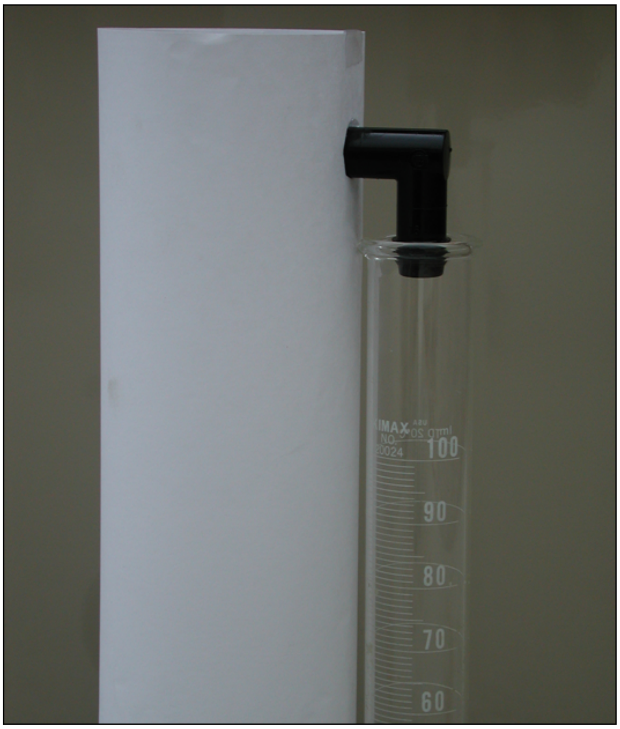
The flotation procedure to measure specific gravity begins with partially filling an appropriately sized graduated cylinder with water, leaving enough room so that the entire cone can be submerged in the water without raising the water level above the graduations. The volume of water placed in the cylinder should be recorded, and the cone then placed in the water. If it sinks, the specific gravity is greater than 1, and the cone is immature.

If it floats, the new water level should also be recorded. The increase in water level is caused by the cone pushing the water up. Because the specific gravity of water is 1 (1 ml of water weighs 1 g), the volume of water displaced (usually measured in milliliters) is approximately equal to the weight of the cone (usually measured in milligrams). Therefore, subtracting the original volume of water from the second volume of water gives the weight of the cone.

Next, the cone should be pushed down until the water just fully covers it. A worker's finger or stick can help push the cone down, but only the cone should be pushed below the water. Only the cone should be measured, not the finger or the stick! This last measurement is the weight of the volume of water displaced by the cone. Dividing the weight of the cone by the weight of the displaced water yields the specific gravity of the cone.

A large cylinder is needed for larger cones. As the graduations of larger cylinders will represent 10 or 20 ml each, water levels will often fall between marks. Estimating the exact water displacement is then required, resulting in greater error in the readings. To control this error, a 2-cylinder system can be used. One cylinder, large enough to hold the cone and water, is equipped with a side spout that can direct any displaced water into a smaller cylinder (figure 4). The second cylinder should be a 100-ml graduated cylinder, which eliminates any need to estimate the exact displacement. To operate this system, the larger cylinder is filled with water until water freely spills out the spout into the smaller cylinder. The water is allowed to drain to its natural level. The small cylinder is then emptied and returned to the spout. The cone is placed into the water, and the overflow collected in the smaller container. Once the dripping stops, which may take a while, the weight of the cone is read directly from the water level in the smaller cylinder. For example, the displaced water volume might be 40 ml. Next, the cone is pushed completely below the water surface. This is best done with a wire, perhaps with a small cradle bent into the end to hold the cone and keep it from rolling. The wire should be kept in the larger container during initial water fill to avoid any bias from its volume. The final amount of displaced water is read after dripping stops. Continuing the example, assume this water volume is 41 ml. This final displacement equals the total volume of the cone. The first displacement divided by the second displacement is equal to the specific gravity. Finishing the example, we divide 40 by 41, which results in a specific gravity of 0.976.

Figure 4—Chapter 3, Seed Harvesting and Conditioning: two-cylinder system for measuring specific gravity of pine cones.



Seed Acquisition

Seed harvesting can begin once a seedcrop of appropriate genetic make-up, adequate quality, adequate quantity, and proper maturity has been identified. However, seed quality must be monitored at the time of collection, for the situation may have changed since first determinations were made. Unexpected seed dispersal, insect-feeding, or other animal predation may have occurred. Certain seeds, such as acorns, can dry out or germinate shortly after they are shed (Bonner and Vozzo 1987; McDonald 1969; Olson 1957). Cones, fruits, and seeds should be cut open and examined again. Sometimes a 10 x hand lens is useful in making a quick evaluation. Prompt collection reduces losses to fungi, insects, and larger animals and birds. Some caution is advised in collecting the first fruits or seeds to be shed from the plant, which may be of poor quality and dropping because of death rather than maturation (Aldhous 1972; Stoeckler and Jones 1957).

Collection. The actual gathering of the seed or fruit from the plant takes many forms depending on the botanical characteristics of the mother plant. The first characteristic important to seed conditioning is the seed-bearing structure. In gymnosperms (for example, pines, spruces, firs, and ginkgo), this is the female strobilus or cone; in angiosperms (for example, all the hardwood trees), it is the fruit. If this structure is not easily removed from the plant or shed naturally, it is classified as persistent. Persistent cones and fruits require more effort to remove them from the plant. Either hard twisting and pulling, or a sharp cutting tool such as pruning shears is needed to sever the connection (figure 5). Alternatively, the seeds are allowed to shed naturally and caught on netting (figure 6). When not persistent, the cones or fruits can be quickly picked by hand or pulled off with rakes, hooks, or vacuum. Another method is to gather cones or fruits from the ground after shaking them from the plant or after natural drop (figures 7 and 8). Yard tools such as rakes, leaf blowers/vacuums, forks, and shovels can be useful in gathering seeds from the ground or off of low plants (figure 8).

In some loblolly, shortleaf (*Pinus echinata* P. Mill.), and eastern white pine seed orchards an extensive system of nets is used to collect seeds. Loblolly cones are very persistent, and much labor and equipment expense is saved by gathering seeds that shed naturally rather than using lift trucks or other devices to pick cones. Problems related to seed maturity are almost totally avoided by relying on natural shedding of the seeds. Avoiding such problems is the strongest attraction of the system in white pine orchards, because the window of time to collect is quite narrow for white pine. The system has several disadvantages, however. There must be enough dry weather during the collection period for natural seed shed to finish by the desired collection date. Predation from insects and larger animals can occasionally be too great, and weed seeds can enter the seedlot from ground plants and vines in the orchard and from droppings of birds that roost in the orchard. Also, family identities are lost in the bulk collection of seeds. This system can be used only for seeds with at least moderate levels of dormancy; nondormant seeds germinate on the netting, resulting in great loss of quality and quantity.

The netting is carpet backing with UV light inhibitors. It is used in widths equal to the distance between rows of trees in the orchard. The individual strips are then drawn together at the edges and fastened with standard wire staples commonly used for paper (figure 9). If the ground is soft, tree shakers are used to shake the seeds from the open cones of loblolly pine, which has a hard seedcoat. As the trees are shaken twice, the shaker actually drives over some seeds that fell on the netting during the first shake. For this reason, shakers cannot be used for eastern white pine, for their seedcoats are too fragile and can be mechanically damaged when the seeds are driven over. Totally natural seed shed must be used in this case. Alternatively, overflights with helicopters can be used, although these are usually too expensive.

Figure 5—Chapter 3, Seed Harvesting and Conditioning: persistent cones or fruit can be cut from the branch with pruning shears.

Figure 6—Chapter 3, Seed Harvesting and Conditioning: seeds from persistent cones or fruits can be caught on netting after natural seed shed as an alternative to cutting the fruit from the branch.

Figure 7—Chapter 3, Seed Harvesting and Conditioning: non-persistent fruits and cones can be shaken from the plant using tree shakers.

Once the seeds are shed from the trees, the netting is rolled up. This is done by a net retrieval machine or simply by drawing the net over itself and piling the seeds in a windrow. The windrow is then combined with a peanut combine to separate the seeds from the bulk of the needles (figure 10). Large quantities of needles are gathered with the seeds, because needle drop occurs at the same time as seeds are shed. The staples holding the netting together pull free easily when the netting is rolled up.

Figure 8— Chapter 3, Seed Harvesting and Conditioning: fruits such as acorns can be gathered from the ground after natural drop.

Location on the plant is another factor determining the method of collection. Cones or fruits near to the ground are generally easily accessible to pickers. Those high in the air require some other means of reaching them. Using cone rakes carried by helicopters (Baron 1986; Haddon 1981) and shooting branches out of trees with a high-powered rifle are methods that are generally safer, faster, and more economical than climbing. Helicopter or rifle harvesting is restricted to species were the cones are clustered on a branch or at the top of a relatively narrow crown such as with spruce or true firs. Shooting the top out of a tree will of course deform the tree; both the rifle and cone rake techniques reduce cone production for a year or 2 at least, because the branch tips that would bear the next crop are removed with the cones. Therefore, climbing is still sometimes the best choice for collecting from tall-growing species. On relatively level land that is accessible by trucks, or in seed orchards, bucket trucks are widely used to lift workers into the crown quickly and with a minimum of personal danger. Another method for obtaining seeds from tall trees is collect them from the tops of trees felled for harvest or fallen over from storm damage (Bonner 1970b). It is important, however, to make certain that the seeds are sufficiently mature when falling occurred. The cones or fruits may appear mature, but the appearance could be due to the general drying of the whole treetop rather than a true maturation. Collection may be necessary promptly after felling to forestall cone opening from high temperatures or losses to birds or mammals. Collecting from felled trees does not always prove cost effective. In some instances fruits or cones shatter or become deeply covered by limbs, tops, and foliage.

Figure 9—Chapter 3, Seed Harvesting and Conditioning: edges of seed collection netting are stapled together at center of rows of trees in a seed orchard.

Figure 10—Chapter 3, Seed Harvesting and Conditioning: a windrow of needles and seed in one method of gathering loblolly pine seed from netting.

Squirrel caches have in the past been used as major sources of cones. This method is now generally avoided because the squirrels cut the cones before they mature, and the cones become heavily infected with fungi in the cache. Both these factors frequently lower seed quality more than is usually considered acceptable.

Purchase. Purchasing cones or fruits from independent collectors is an alternative to collecting the material directly. Independent collectors can range from the general public to professionally trained consultants. The relationship between collector and buyer may be totally informal, with people walking in off the street on the day of purchase, or it may involve a formal written contract that describes specifics of the harvest. The explicit formal arrangement provides the greatest guarantee of correct genetic source, species identity, and seed quality. However, successful collections have been made by buying from the general public. Whatever system is used to acquire cones and fruit, the important point is that there must be reasonable assurance that the correct species, genetic source, and quality are acquired. If any doubt exists about these factors, it is absolutely essential to modify the procedures to provide reasonable assurance.

Cones or fruits, especially those purchases from the general public, who may not be as knowledgeable or committed to quality as might be desired, must be inspected thoroughly. Containers of fruits or seeds need to be emptied for inspection. A rough cleaning can be done at this point to remove leaves, sticks, stones and other tramp items to obtain a truer volume or weight. A grading table is useful for making this inspection and for quick repackaging. A table for cones and larger fruits can be made from wooden slats measuring 2.5 by 5 cm (1 by 2 in) placed 2.5 cm (1 in) or less apart (Lott and Stoleson 1967). Litter can fall through the slats and the fruits can roll down the table to be repackaged (figure 11). Larger pieces of trash can be hand picked. Cutting or x-raying fruits and seeds is also necessary at this time to verify proper development and maturity.

No matter how the seeds, cones, or fruits were collected, it is best to minimize the amount of trash that is brought in with them. Needles, leaves, grass and other debris that are collected with the fruits will fragment during drying and handling and generally increase the difficulty of cleaning the seed. Such debris should be separated during collection if feasible, or, when not feasible at collection, upon arrival at the seed plant. Tumblers and large flat screens have been successfully used to do this mechanically.

Lot identity. Maintaining the identity of the seedlot is critical. All the work of collection can come to nothing if the identity of the seedlot is lost. Therefore, all containers need to be precisely and carefully labeled. A unique seedlot (identification) number needs to be written on tags placed both inside and outside of the containers. The outside tag is usually enough and is accessible for easy inspection. The inside tag is easy insurance in case the outside tag is removed. Identification numbers should be simple; a long complicated number increases the chance that error will occur as the number is transcribed. The species name or initials, the year, and an accession number should be sufficient. Additional information should be kept in a record book, rather than incorporated into a complicated code. One aid to maintaining seedlot integrity is the use of official seed certification. This system (see chapter 6) and Karrfalt 1996) is most useful if seedlots are being bought and sold among many parties. It is particularly useful when seed buyers do not have first-hand knowledge of the collections or the seed company.

Transportation. A variety of rigid and nonrigid containers are available to transport fruits. Cones are shipped in bulk, in sacks, or in wire-bound boxes. New containers or ones that can be thoroughly cleaned should be used to prevent physical or pathological contaminants from getting into the seed. Bags may be completely filled when cones are to be in them for only a short time; however, for any temporary storage, bags should be filled only half-way. One bushel of cones goes well in a 2-bushel sack. Space is thus left for expansion of scales as cones dry. Otherwise, scales may dry in the closed position or partially closed position, severely impairing seed extraction. This condition can sometimes be overcome by wetting or soaking the cones and redrying. However, allowing scales to dry in a closed position results, at best, in extra work and time delays that can be completely avoided by leaving more space in the bags. Bags made of material having a tighter weave than burlap may be needed for small dry fruits or seeds. Never use an unventilated bag, such as one made of plastic, for cones or fruits that need to dry. Unventilated bags lead to loss of seed quality, because of molding and heating. Wire-bound boxes make good transport containers. Their main advantage is that they can be handled mechanically. They also hold a relatively large amount of seeds but not so much that aeration is inadequate for maintaining seed quality. These boxes are widely used for southern pines.

Figure 11—Chapter 3, Seed Harvesting and Conditioning: a grading table for quick inspection and cleaning of cones or fruits (Lott and Stoleson 1967).

Seed Cleaning and Conditioning

Post-Harvest Storage

Post-harvest storage is the period between collection and the preparation of the seed for planting and long-term storage. (For a discussion of long-term storage, see chapter 4.) At this stage, seeds are grouped according to their ability to be dried and whether the fruit is fleshy or not fleshy. Seeds that cannot be dried are called recalcitrant. These include the seeds of oaks, chestnuts (*Castanea* spp.), buckeyes (*Aesculus* spp.), many tropical hardwoods, and some maples (*Acer* spp.). These seeds cannot be allowed to dry. Premature germination or deterioration can occur as a consequence of the high moisture. Therefore, these species require cool storage or, if the species is injured by chilling, immediate planting. Storage near freezing is often best with temperate species, as long as ice does not form, which would cause cell damage and death. If controlled near-freezing storage is not available, seeds may be hold in a cellar, air-conditioned room, or shaded spot. To maintain the high moisture content of recalcitrant species, it is helpful to seal them in moistureproof containers, usually plastic sacks, or to add moisture to compensate for drying losses (Bonner 1973; Bonner and Vozzo 1987; Tylkowski 1984).

Those seeds that can be dried are referred to as orthodox. Orthodox seeds are broken into 2 groups:

- fleshy fruits—for example, those of dogwoods (*Cornus* spp.), cherries (*Prunus* spp., and junipers (*Juniperus* spp.)
- non-fleshy fruits—for example, those of ash, elm (*Ulmus* spp. L.), and pine

Fleshy fruits must be prevented from drying until the pulp is removed, otherwise the pulp hardens and is then not easily or adequately removed. Pulp is generally removed to make handling easier and to control fungi or bacteria that can grow in the pulp. As with recalcitrant species, the fleshy-fruited orthodox seeds must be kept cool and ventilated to prevent the buildup of heat and subsequent deterioration. They may be treated basically the same as the recalcitrants; however, fleshy-fruited orthodox seeds might require more ventilation because of higher moisture content.

The dry-fruited (also referred to as non-fleshy) orthodox species should be allowed to dry to prevent deterioration. High moisture in these fruits usually leads to heating, molding, and subsequently, loss of viability. Spreading the seeds on screen racks is an economical way to dry these fruits. Minimal drying is necessary during post-harvest storage when the seeds are collected dry. Post-harvest storage conditions usually need to allow for the loss of moisture at a gradual rate and to protect the seeds from the weather. If the fruit expands upon drying (for example, a pine cone), sufficient space must be allowed for expansion. Otherwise the fruit will become case-hardened and the seed locked inside the fruit as discussed previously. Figure 12 shows wire-bottom racks for air-drying cones under shelter. Alternatively, moisture must be maintained at a high level to prevent the expansion of cones. Because high moisture can lead to seed deterioration, it is important to evaluate a system that keeps orthodox seeds moist to be sure there is no loss of seed quality. Cones in full sacks or in bulk must be re-bagged into half-full sacks or placed in ventilated storage. Drying racks with cones spread out about two cones deep are very good. Cones have also been successfully stored in temporary cribs of snow fencing 8 to 10 feet in diameter. Storing cones in this type of crib or in 35-liter (20-bushel) wire-bound boxes ventilates the cones but also keeps them from drying and loosing their seed. Both cribs and boxes are used out of doors. Cones should never be stored in a large pile as this will result in heating. Smaller piles will cause many surface cones to open and the seeds will be lost. Also, piling cones on the ground invariably leads to stones in the seedlot.

Fruiting structures (that is, cones) that are serotinous require additional consideration; such cones require a brief period of very high temperature to melt resin seals that prevent cones from opening. In nature, this happens after forest fires. In North America, lodgepole pine, jack pine, sand pine, and black spruce have serotinous seeds. Black spruce seeds require a high initial kiln temperature only. The pines generally need a hot water dip or a steam treatment. This operation must often be done immediately after harvest, because not all trees will produce serotinous cones or the same degree of serotinony. Therefore, some cones will begin to open without the heat treatment, exposing some of the seeds to lethal temperatures when the treatment is done. The heat treatment can be delayed if it is absolutely certain that all cones will remain closed. The treatment cannot be done on seedlots with some open cones without losing seeds. The treatment must be hot enough and long enough to release all cones, otherwise, the undesirable situation of some cones open and some completely closed will be created artificially. Generally, the treatment is for 30 seconds or less, with boiling water or live steam. As the seal is broken, the cones often crackle. When the crackling has stopped, the cones are adequately treated. If the operator lacks experience in this procedure or faces new conditions, it is best to run a small trial batch to be sure the procedure is properly timed. Germination of the seeds should be tested to evaluate the procedure. The discussion on quality control later in this chapter explains how to do this.

Figure 12—Chapter 3, Seed Harvesting and Conditioning: screen bottom trays under shelter for air-drying dry fruits.

Species vary considerably in tolerance to high moisture and the length of time that they can be at high moisture. This tolerance is related to the degree of dormancy to germination. Some species—such as cottonwoods and aspens *(Populus* spp. L.) and red maple (*Acer rubrum* L.)—are all orthodox but require rapid drying and processing to maintain highest viability. Species with dormancy to germination—such as white pine, white ash (*Fraxinus* americana L.), and tuliptree (*Liriodendron tulipifera* L.)—can be held for relatively longer periods without loss of viability. How long a species can remain in post-harvest storage is the critical factor in determining the work schedule. Those without dormancy must be dealt with first and dealt with rapidly enough to preserve their viability.

Seed Extraction

Extraction is the first step after post-harvest storage. In terms of extraction, fruits are classified as being single or in clusters, fleshy or non-fleshy, dehiscent or indehiscent. Seeds in clusters (for example, those of ash and maple) must be singularized so they will flow easily through cleaning and planting machines. Fleshy fruits—for example, those of cherry and dogwood—are usually de-pulped for ease of handling and to control pathological problems. Indehiscent or unopened fruits—for example, those of black locust (*Robinia pseudo-acacia* L.) and manzanita (*Arctostaphylos* spp.—can be hulled to remove the seed from the fruit. The dehiscent dry fruits—for example, those of sweetgum and spruce—can be tumbled or shaken to separate the seeds from the fruit following drying.

Fleshy fruits. De-pulping fleshy fruits, such as those of magnolia and chinaberry, is done using a macerator, grinder, or mill that is carefully adjusted to avoid seed damage. It does not matter if the fruits are in clusters or single–de-pulping also singularizes the seeds. Macerators are most often used to depulp fruits (figure 13). The most common design uses a flat spinning plate on the bottom of a roughly 26-liter (7-gallon) can. The plate has 4 bars arranged in a 90-degree cross on the bottom. These bars strike the fruits and burst them. The abrasion of fruit against fruit also breaks up the fruits. Water is run into the can while macerating to wash away the separated pulp. Some machines have an angled baffle just above the spinner plate to force the fruit against the plate, creating a squeezing motion. Another refinement involves lining the can with hardware cloth or striking the outside of the can with a punch to create bumps on the inside. A 3.8-liter (1-gallon) can is then bolted to the spinner plate with the retainer nut for the spinner plate. This can is also wrapped with hardware cloth (figure 14). The addition of these rough surfaces decreases maceration time by 50 to 75%. The flow of water into the can is also improved by installing a ball valve directly to the side of the can. Water is then added to the seed simply by attaching a water hose to the valve and turning the valve (figure 15). This feature saves time and prevents pulp from being splashed on the operator.

A food blender can be used as a small-scale version of a macerator. Cover the blades with rubber or plastic tubing to prevent the seeds from being cut. About 240 ml (1 cup) of fruit at a time can be cleaned with this small macerator. The pulp must be rinsed and floated away in a separate operation.

A grinder (figure 16) can also be used to de-pulp fleshy fruits such as those of dogwood, blackberry, and cranberry. This grinding step is followed by a separate washing operation to rinse the pulp away. The grinder must be adjusted carefully to avoid crushing or cracking the seeds.

The pulp is easiest to remove if softened first. The flesh is ideally ready when it can be smashed between thumb and fingers. A 3- to 10-day running water soak will usually soften the fruit to the desired condition. Changing the soak water daily is an acceptable alternative to having running water. Some fruits—such as crabapple (*Malus pumila* P. Mill.)—are very hard and require more severe treatment. Crushing under vehicle tires or a fruit crusher or freezing followed by a storage period for fruit deterioration are needed for these hard fruits. However, it is vital to avoid any

Figure 13—Chapter 3, Seed Harvesting and Conditioning: a common type of macerator for de-pulping fleshy fruited seeds.

Figure 14—Chapter 3, Seed Harvesting and Conditioning: maceration time is reduced by adding to the macerator a hardware cloth liner and a can wrapped with hardware cloth.

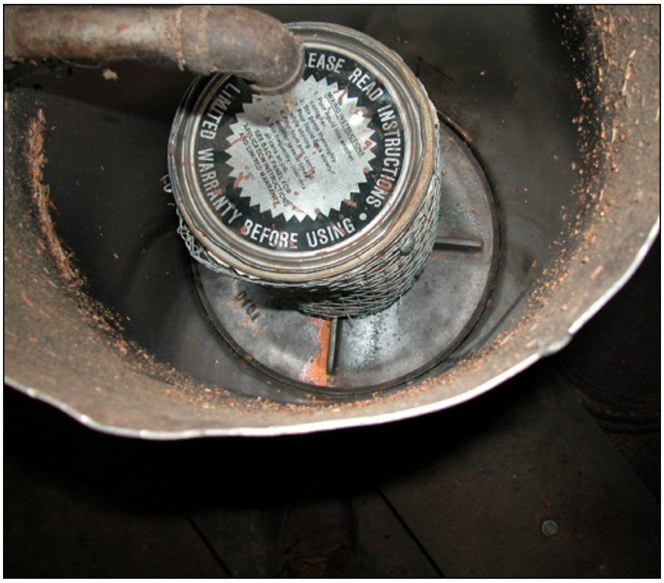
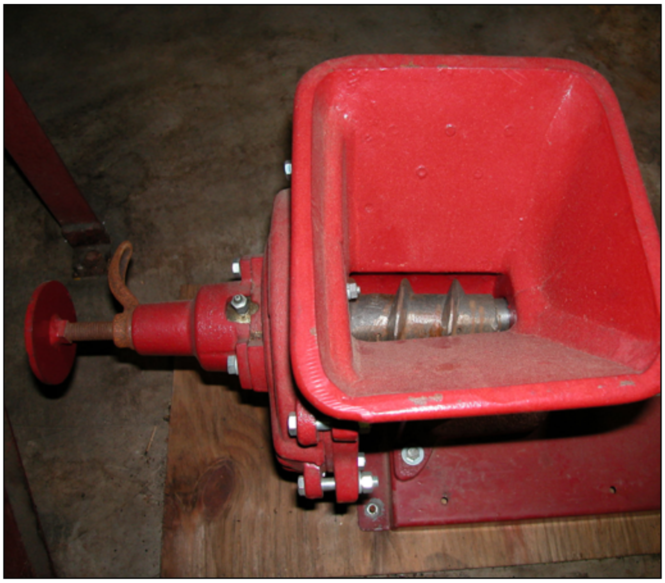


Figure 15—Chapter 3, Seed Harvesting and Conditioning: a water Chapter 3, valve installed on the side of the macerator improves ease of operation.

heating or fermentation during these steps to soften the fruit, for any buildup of high temperatures or alcohols from fermentation can be lethal to the seeds. However, regular exchange of soak water will easily prevent this problem.

Dry fruits. Non-fleshy, or dry, orthodox fruits or seed-bearing structures—for example, those of pine, larch, and sycamore—usually require drying as a first step for both dehiscent and indehiscent types. The most common way to achieve this is to heat ambient air to temperatures that result in the relative humidity dropping to about 30%. Some locations have air that is naturally dry and require little or no heat to achieve the necessary drying conditions. Other locations may have high ambient relative humidities, which must be measured to be certain an adequate drying temperature is used. In many locations the ambient conditions can fluctuate, and the drying temperature should be adjusted to meet the current conditions for best economy and efficiency of drying. Always using the same drying temperature could result in using a temperature higher than necessary, wasting fuel, or a temperature that might not dry the air enough. Table 4 shows what the maximum ambient relative humidity can be for a given drier temperature and ambient air temperature combination, while maintaining relative humidities of 30% or less in the drier. The numbers in the body of the table are the maximum ambient relative humidities. For example, at 20 °C and 65% RH, a drier temperature of 30 °C is too low, because the maximum permissible ambient RH is shown as 58. In this case, it would be necessary to use a drier temperature of 35 °C , for which the maximum permissible ambient RH is 71%, as shown in the table. The maximum drier temperature that should be used is 43 °C. If this temperature must be exceeded to obtain dry air, first dry

Figure 16—Chapter 3, Seed Harvesting and Conditioning: a grinder can also be used to crush fleshy fruits for seed extraction.



the air by cooling with an air conditioner. When treating serotinous or semiserotinus cones (for example, lodgepole pine or black spruce), it might be necessary to use temperatures in excess of 43 °C.

A well-constructed pressurized drier is needed to effectively use the dry air produced by heating. A laboratory model of a pressurized drier is shown in figure 17. The fan on this drier forces air into the box or plenum and the screen that holds the seeds is laid on top of the box. The drier becomes pressurized once the screen is covered evenly with seeds, causing the air to be uniformly forced through the seeds. The box containing the seeds must fit on the plenum with an airtight seal to provide the pressurized condition. If the drier were not pressurized, the air would take the path of least resistance and go around the seeds, drying only the surface layer of seeds. Inner layers would dry much more slowly. Pressurizing ensures that the seeds inside the seed mass are drying as well as seeds on the surface and that all the air is used for drying rather than simply passing by. Pressurizing the drier, therefore, gives more uniform, rapid, and efficient drying. Without pressurizing, the seeds, cones, or fruits need to be spread loosely so that air can easily pass over and among the material. Alternatively, the material can be stirred several times an hour, but this is not practical during the night or with large quantities.

Figure 17—Chapter 3, Seed Harvesting and Conditioning: laboratory model of a pressurized seed drier.

After drying, dehiscent fruits and cones such as sweetgum or pine can be tumbled or shaken to remove the seed from the fruit (figure 18). Indehiscent fruits can be hulled to remove fruit walls or wings or to singularize. Removal of fruit or wings and singularization are done usually in a single step. Some fragile fruits (for example, those of red maple) can only be singularized and not de-winged. Hammer mills or scarifiers have been used for hulling but might be too destructive (Young and others 1983). Tough legumes—for example, those of honey-locust (*Gleditsia triacanthos* L.)—have also been successfully broken up in a concrete mixer by adding small pieces of broken-up concrete. Debearders are also used. One that has been found to be very versatile and safe for the seed is the brush machine (figure 19) (Karrfalt 1992). In this machine, the fruit is rubbed against a slightly ovoid wire sleeve by rotating brushes. This sleeve is called a shell and can be made of coarse wire for much abrasion or fine wire for less abrasion. The brushes can be of varying degrees of stiffness ranging from very fine hair brushes to stiff nylon. Adjustments can also be made for the speed at which the brushes turn, how

Table 4—Chapter 3, Seed Harvesting and Conditioning: maximum recommended ambient relative humidity values for drying seeds, cones, and fruits with heated air at various drier temperatures from 24 to 43 °C

Ambient air temp (°C)	Relative humidity (%)							
	24 °C	27 °C	29 °C	32 °C	35 °C	38 °C	41 °C	43 °C
4	100	100	100	100	100	100	100	100
7	78		100	100	100	100	100	100
8	57	75	94	100	100	100	100	100
9	66	86	100	100	100	100	100	100
11	50	65	77	88	100	100	100	100
16	44	58	68	78	94	100	100	100
18	39	51	60	65	84	95	100	100
20	31	42	50	58	71	81	95	100
22	30	38	45	49	65	69	82	100
24	30	31	38	45	55	63	74	87
27	30	30	35	38	47	54	64	75

tightly they press against the shell, and how long the seeds are retained in the machine. The fruits need to be dry for the hulling operation to work well. The effect of hulling with a brush machine can be seen in figure 20. A partial list of genera and species that can be successfully de-winged or hulled with the brush machine includes ash, maple, tuliptree (*Liriodendron tulipifera* L.), southern catalpa (*Catalpa bignonioides* Walt.), black locust, sycamore, big sagebrush (*Artemisia tridentata* Nutt.), mountain-mahogany (*Cercocarpus montanus* Raf.), and winterfat (*Krascheninnikovia lanata* (Pursh) A.D.J. Meeuse & Smit)

Conifer seeds. Conifer seeds are usually de-winged after tumbling from the cone. De-winging can be done either wet or dry. Some species, white pines, for example, separate easily when tumbled in a drum such as a concrete mixer. Others—for example, hard pines and spruces—require adding a small amount of water to the seeds as they are tumbled to release the wings. In other machines, pressure can be applied with brushes or paddles to remove wings from dry seeds. A mortar mixer is an example of a machine commonly adapted to the dry de-winging of conifer seeds with a modest amount of pressure. However, using pressure increases the chance of mechanical damage. To minimize the amount of mechanical injury, the paddles should be slowed by changing gears on the mixer and de-winging the seeds for only a limited time. A timer switch can be used to easily control de-winging time. The Missoula small-lot pine seed de-winger (figure 21) is another commonly used machine that rubs wings off. It has been particularly widely used in the West and has de-winged millions of pounds of seed. However, if liners are improperly installed, liners or flaps selected improperly, or flaps turned too fast, serious seed damage can result. As always, proper use of equipment is essential.

Figure 18—Chapter 3, Seed Harvesting and Conditioning: a tumbler can be used to extract seed from dehiscent cones or fruits.

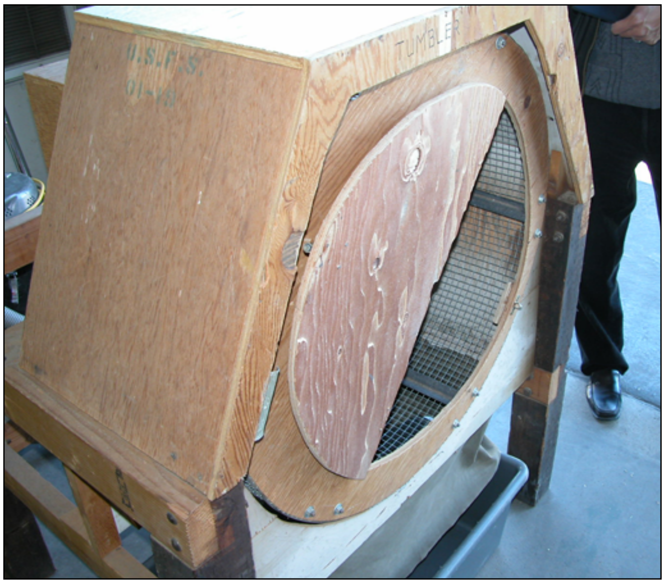


Figure 19—Chapter 3, Seed Harvesting and Conditioning: brush machine used for hulling indehiscent fruits, de-winging, and singularizing seeds.

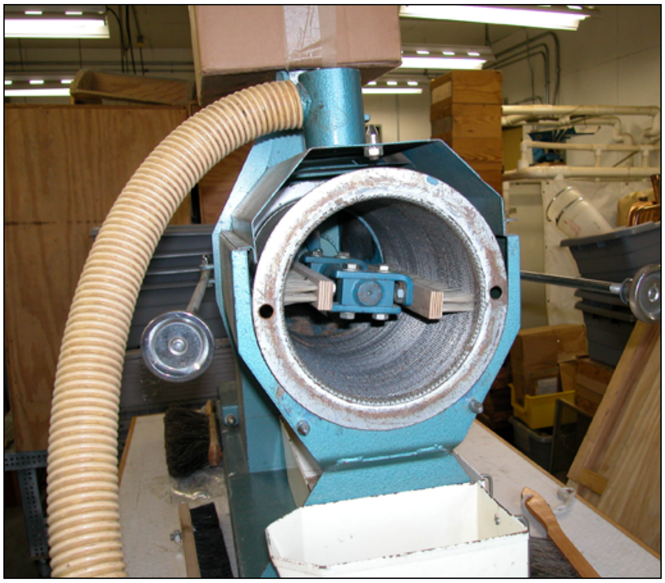


Figure 20—Chapter 3, Seed Harvesting and Conditioning: tuliptree and green ash seeds after treatment with the brush machine.

Because wet de-winging presents minimal chance of mechanical damage, it is the preferred procedure when appropriate. Wet de-winging is accomplished generally by tumbling the seeds in a rotating drum in the presence of an intermittent fine water mist. The drum can be simply a small concrete mixer (figure 22) or it can be a special-order machine (figure 23). The water can be added by computer-controlled valves or sprayed on with a hand sprayer. Intermittent compressed-air spray can be used to partially dry the seeds and blow the wings out of the drum. The compressed air and the water are alternated with each other until the de-winging is finished. Without the compressed air in the drum, the seeds need a quick pass through an air cleaner to blow out the wings. Wet de-winging requires immediate drying after de-winging to prevent deterioration. The drying is brief, because the moisture is near the surface of the seeds. The pressurized drier described previously is also best for this drying.

Some conifer seeds (longleaf pine and true firs, for example) have a wing that is one structure with the seedcoat. These wings must be removed with care; for some particularly fragile species such as true firs, the seed plant operators sometimes opt not to de-wing.

If the wings need to be rubbed from the seeds it might be necessary to remove large or abrasive trash from the seedlot first. This is called scalping and is done with a screen machine.

Figure 21—Chapter 3, Seed Harvesting and Conditioning: small-lot pine-seed de-winger developed by the USDA Forest Service's Missoula Technology and Development Center, Missoula, Montana.

Another factor to keep in mind before de-winging is the separation of particles from the seedlot that are of equal size and weight to the finished seeds. These are sometimes all but impossible to remove from the finished product.

Figure 22—Chapter 3, Seed Harvesting and Conditioning: small mixer for tumbling seeds for wet and dry de-winging; the spray bottle is used to apply water for wet de-winging.

Figure 23—Chapter 3, Seed Harvesting and Conditioning: commercially made wet pine-seed de-winger.

However, before the wing is removed, the seeds will be very much lighter than the trash in an air column. This is the case with species that have a great deal of pitch in them such as western larch. A sensitive air column can blow the seeds up and let the pitch or other trash fall, giving a perfect separation.

Cleaning and Upgrading

Basic cleaning and upgrading steps for orthodox hardwoods, shrubs, and conifers become similar once the seeds are extracted, de-winged, and dried. Basic cleaning is accomplished with air-screen machines, screens, aspirators, and blowers (figures 24–27). These devices have historically been the workhorses of seed cleaning.

Removing trash with air. Air can be used to remove particles that are either lighter or heavier than the seeds. Dust, small pieces of pine needles, leaves, and wings are examples of lighter materials that can be taken out of seeds using air. The removal of pitch from conifer seeds is an example of using air to remove seeds from heavier particles. Aspirators use negative pressure by having the fan placed above the seeds. Blowers, on the other hand, use positive pressure by placing the fan below the seeds. Either approach works well if the air can be applied uniformly, constantly, with enough force, and varied precisely so that a high level of control over the force of the air is acheived. Without precise control, only the coarsest separation would be possible. The more refined the air control, the more refined the separation. Air-screen machines, blowers, and aspirators can all accomplish good air separations, but not all models of machines have the same degree of control over the air and, therefore, different quality of work can result.

Removing trash with screens. While air is used to clean seeds by weight, screens separate seeds from trash according to width and thickness. Screens are made either by punching holes in sheet metal to make perforated metal screens or by weaving wire together to make screens that resemble those used for home windows. The perforated metal screens are most common, the woven wire (figure 28) less common, being used generally for very fine seeds such as those of eucalyptus (*Eucalyptus* spp.) and grass. The perforations are mostly made in round or oblong hole sizes (figure 28). Screens made in the United States are measured in 64ths of an inch; screens made in other countries are measured in millimeters. As an example, the holes in a U.S.-made number 8 round-hole screen are 8/64 of an inch in diameter. [Note: Some authors have described using soil screens, which have an entirely different size description system, for extracting seeds from fleshy fruits.]

Figure 24—Chapter 3, Seed Harvesting and Conditioning: air-screen machines come in many sizes and are used for basic seed cleaning; a small-seedlot cleaner is in front of a very large capacity cleaner.

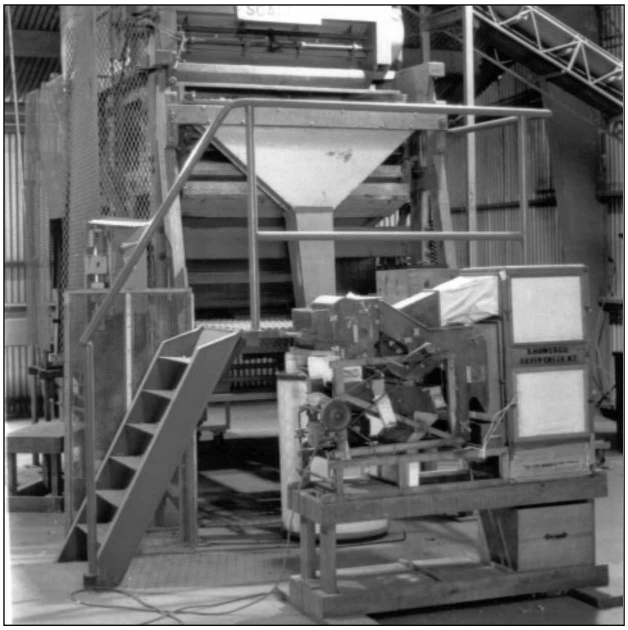


Figure 25—Chapter 3, Seed Harvesting and Conditioning: cleaner–sizer machine has 5 screens to give 6 separations at once.

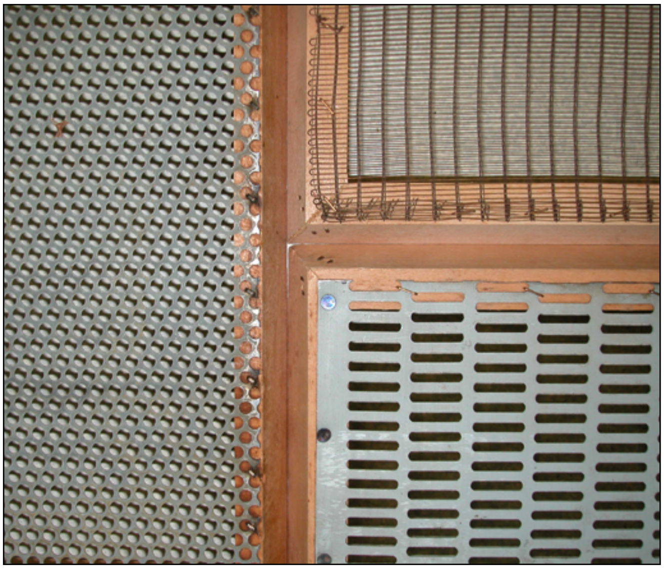
A proper selection of screens is necessary to get the desired separations. First, it must be determined if seeds need to be separated by their width or thickness. In cross-sections of seeds or trash particles, the dimension that is greater is the width and the lesser dimension is the thickness. Round-hole screens sort for difference in width,

Figure 26—Chapter 3, Seed Harvesting and Conditioning: a laboratory aspirator removes trash with vacuum.

Figure 27—Chapter 3, Seed Harvesting and Conditioning: a laboratory blower removes trash with positive pressure.

oblong-hole screens for difference in thickness. An example of a thickness separation is the sieving of flattened immature seeds out of redbud (*Cercis canadensis* L.). Slotted screens easily remove the wire staples that get into pine seeds when net collection systems are used. The separation of cone scales from pine seeds is another example of separation by width.

Figure 28—Chapter 3, Seed Harvesting and Conditioning: hand screens showing the 3 main types of screens used to clean seedlots (**counter-clockwise from left**): perforated metal round hole, perforated metal oblong holes, and woven wire.



After the correct type of hole has been determined, the proper size of hole is selected. Several screens are stacked on top of each other with the largest size screen on top and each successive screen the next size smaller. As an example, screens could be stacked from top to bottom in this order: 12, 11, 10, 9. The next step is to pour a sample of seeds on the stack of screens and shake the stack back and forth. Disassembling the stack reveals which sizes made the best separation. Typically, one size will hold both seeds and trash. A decision must be made whether to keep some trash in the seeds, discard some seeds with the trash, or take the mixed fraction and separate it in some other manner. When trash is left in the seeds, we are saying that we can live with that level of contamination. When some seeds are discarded with the trash, we are saying that we can afford to loose some seeds because the higher level of purity is worth the cost of the lost seeds. When the mixed fraction is cleaned, we are saying we need all the seeds but cannot afford the lower purity and are willing to pay for extra cleaning.

Once the screens have been selected, the air-screen or screen machine should be set up. In a 2-screen machine, the top screen would be the one that held the most trash and the bottom screen the one that passed the desired amount of small trash. Remember that there might be a few seeds in the large trash or the small trash so that purity is higher, or some trash may be left in the seeds to keep every seed possible. For machines with 3 or more screens, additional fractions can be created. The effectiveness of the screen in the machine is determined by the speed of the shake of the screen, how well the screens are kept from blinding, and the feed rate; in some machines the slope of the screen is also adjustable.

Blinding occurs when the seeds or trash particles drop into a hole and can neither fall through nor bounce out (figure 29). This of course reduces the effective area of the screen. There are 3 types of devices to clear the holes: tappers, brushes, and ball decks. A tapper hits the screen to jar out any particles. Brushes are pressed against the bottom of the screen and pulled back and forth by ropes or cables. The brushes directly push the seeds out of the blinded holes. Ball decks consist of a cage attached to the bottom of the screen that contains small rubber balls. These balls bounce against the bottom of the screen and jar the seeds out of the blinded holes. Ball decks are now generally used on new machines, because they are easier to maintain than other devices and increase the capacity of the screen. They can also be put on many older machines to replace brushes and tappers.

Air and screens can be used to separate by particle width, thickness, and weight. However, they are generally unable to separate by particle length. Only the riddler screen (figure 30) can separate by length; this screen is used with a pulsing shake instead of the more steady shake of the standard air-screen machine. The holes in this screen have a right-angle bend in them. The long particles are unable to turn the corner and are walked up the screen by the shake. Short particles make the turn and pass through. The riddler screen is used principally in making dockage tests (a type of purity test) on grain, but has been used on a limited basis to clean trashy lots of tree and shrub seeds. Needle fragments can be removed from loblolly pine seeds with this type of screen.

Removing sticks and needles. Removal of sticks, stems, or needles from seeds is an example of length separation. Length separations are usually done using indent discs or indent cylinders (figure 31). An indent cylinder can remove stems from hardwood seeds that are not removed by basic cleaning. Seeds in an indent separator settle into the indents of the cylinder and are lifted as the cylinder is rotated. The stem piece also fits into the indent, but because it is longer its center of gravity is outside of the indent and subsequently it falls out of the indent before the seeds will (figure 32). The stem falls back to the bottom of the cylinder while the seeds are carried up and dropped into a collection trough. The indents need to be large enough to let the seeds seat completely. The speed of cylinder rotation and the angle of the collection trough are also adjusted to obtain the separation.

There are a few ways to perform length separation when an indent cylinder is not available. These techniques usually do not work as effectively but can be helpful. The first is to use flat screens with the upper portion of the screen covered with a sheet of paper (figure 33). The paper allows the seeds and long trash to travel parallel to the screen before encoun-

Figure 29—Chapter 3, Seed Harvesting and Conditioning: the seeds caught in the screen holes are said to have "blinded" the screen.

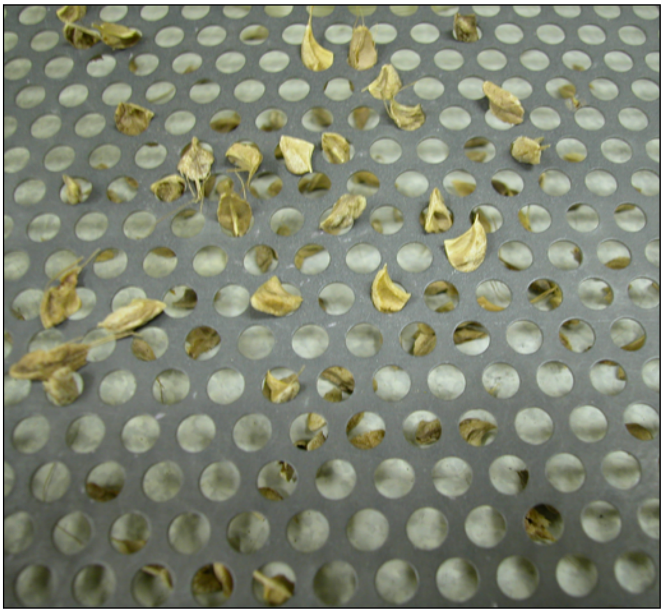
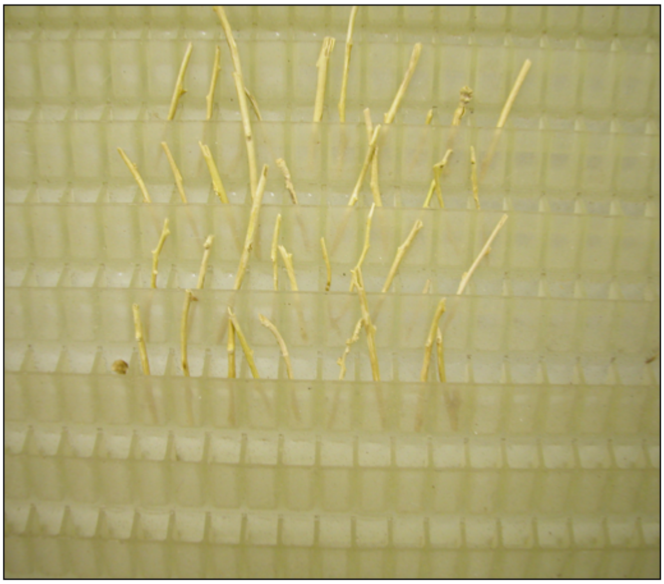


Figure 30—Chapter 3, Seed Harvesting and Conditioning: pine needles separated from seeds using a riddler screen.



tering a hole. As a result, the long particles, the sticks, tend to ride over the hole while the short seeds fall through. Without the paper, the sticks come endways towards the hole and, having a small dimension, their diameter, in line with the hole, drop straight through. Several passes will usually be required for this procedure to remove most of the sticks.

Sometimes the sticks will be removable with air because of their aerodynamic properties. Even though they may be heavier than the seeds, they catch the air well and can be lifted away. Similarly, the sticks may float to the bottom of the specific-gravity table by the process described below.

Removing trash with static electricity. Electrostatic separators also separate by weight using the force of an electrostatic field instead of air to make the separation. Charges on the particles cause them to be drawn to a negatively charged plate. Picking up small pieces of paper with a piece of plastic that has been vigorously rubbed with a dry cloth is a simple example of using an electrostatic force to pick up a light particle. One type of electrostatic separator is shown in figure 34. Electrostatic separation has had little application with trees and shrubs and only with light-seeded species (Karrfalt and Helmuth 1983). A glass beaker rubbed on the inside with a nylon or other synthetic cloth makes a simple type of electrostatic cleaner for very small seedlots. Uncleaned seeds are poured into the rubbed beaker and rolled against the sides of the beaker. After the trash has clung to the sides of the beaker, the clean seeds can be poured out. Plastic cups can substitute for the glass beaker.

Figure 31—Chapter 3, Seed Harvesting and Conditioning: indent cylinder machine for removing needles, sticks, and stems from seeds.

Figure 32—Chapter 3, Seed Harvesting and Conditioning: seeds are caught in indent cylinder while pine needles slide away

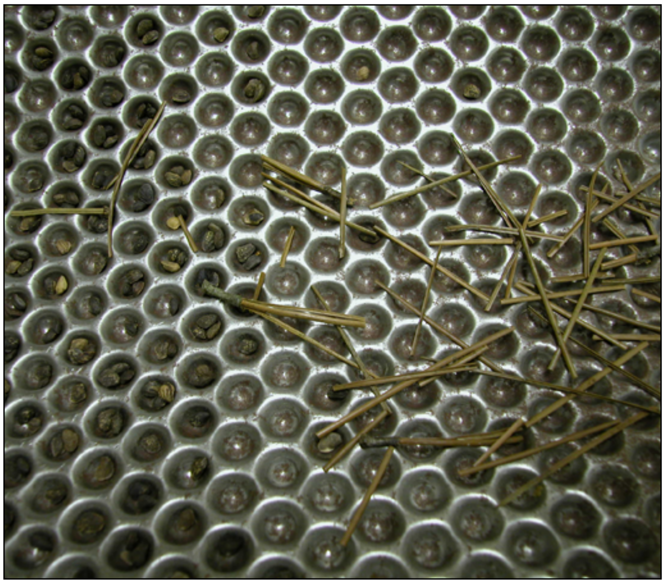
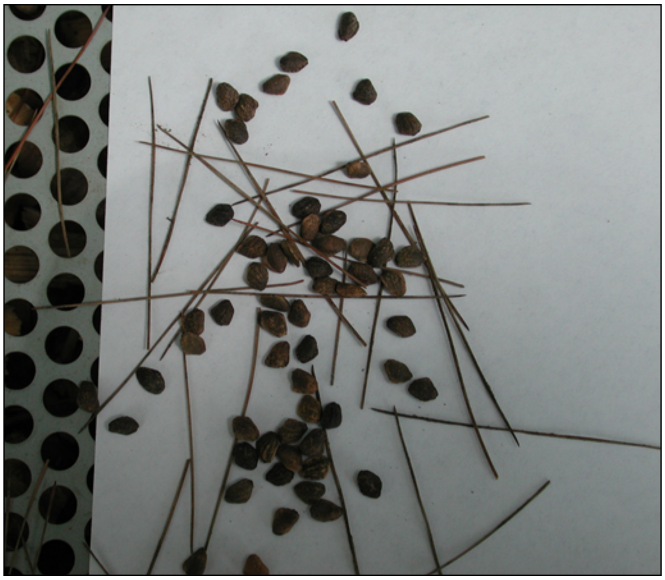


Figure 33—Chapter 3, Seed Harvesting and Conditioning: paper on screen aids in screening-out needles and sticks.



Removing trash by rolling and sliding. Another characteristic that can be used to separate seeds and trash is surface texture, or the ability to slide or roll down a slope. Conifer seeds, especially larch or white pines, can contain a large amount of pitch. The pitch particles have a sticky surface whereas the seeds are relatively smooth. The vibratory separator (figure 35) is often able to use this difference to remove the pitch. This separator consists of a 22.9-cm-square (9-inch-square) deck mounted on a variable-speed vibrator. The deck has adjustable side and end tilt. The vibration causes the pitch, which grips the deck surface because it is tacky, to walk up the slope while the seeds, which are smoother, slide down the slope. The rate at which seeds are fed onto the deck, the speed of deck vibration, the roughness of the deck, the degree of side and end tilts, and the arrangement of the cut gates are all important. Trial and error determine what adjustments are necessary to get a separation.

Not all pitch will separate on the vibratory separator. Some may be too dry and, therefore, too smooth to stick to the deck well enough. Other pieces of pitch may be too round. Screening will sometimes work in these cases.

Another approach to surface texture is to modify it. Sometimes pitch can be removed with a gravity table (see section below on gravity tables), but only after it has been very well dried or stiffened by placing the seedlot in a cooler or freezer (Zensen 1980). This drying or cooling keeps the seeds from balling up around the pitch particles.

Another type of machine that separates by particles' ability to roll is the inclined draper (figure 36). This machine is a variable speed belt that can be set at different slopes. Particles that are round, or able to slide more easily, go down the slope while the flatter particles with greater friction ride up the hill on the moving belt and are placed in the upper collection box. Separating juniper berries from juniper leaves is an example of a separation that can be done with the draper. A board with a piece of cloth over it makes a simple draper for a small quantity of seeds. A handful of seeds can be cleaned at one time with this board. The seeds are allowed to roll down the board and then the needles are manually dumped off.

Spiral separators also use rollability. These are made of two concentric metal spirals. Seeds are poured into the top of the inner spiral. As they slide down the spiral, the round particles roll and gain momentum, causing them to fly out of the inner spiral into the outer spiral. Trash can be removed from dogwood and juniper berries in this manner (Delany 1998).

Improving quality with specific gravity tables. Specific gravity tables are another class of machine that separates by weight (figure 37). Gravity tables can be used on almost any species of seed that flows freely. They have been very successful in cleaning true firs, longleaf pine, tuliptree, and sycamore when other methods have not provided the desired results. The separations are made in the following manner. Seeds are fed onto a wire or cloth deck that has air blowing through it from below. This air is just enough to cause the seed mass to fluidize, with the lighter material floating to the top. Only enough air is applied to slightly lift

Figure 34—Chapter 3, Seed Harvesting and Conditioning: diagram of one type of electrostatic separator.

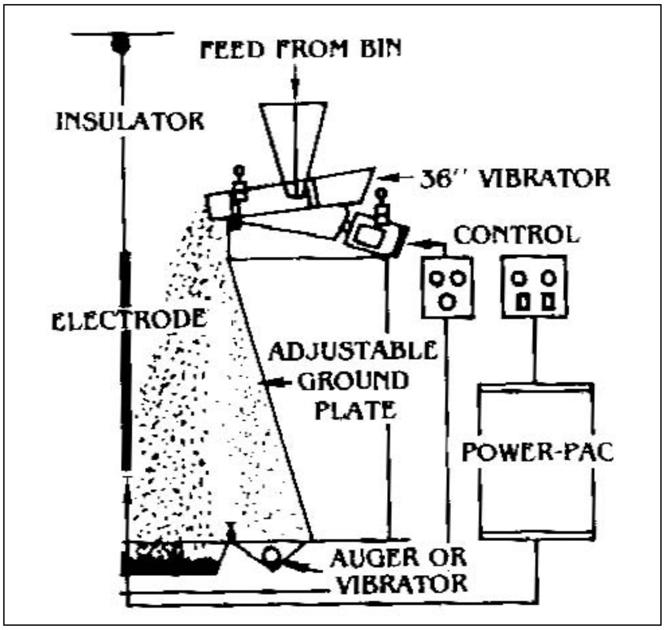


Figure 35—Chapter 3, Seed Harvesting and Conditioning: the vibratory separator removes trash from seeds by differences in surface texture.

Figure 36—Chapter 3, Seed Harvesting and Conditioning: the inclined draper separates particles on their ability to roll or slide down the inclined belt.

Figure 37—Chapter 3, Seed Harvesting and Conditioning: a specific gravity table for separating seeds and trash by weight.

the lighter material, not toss it into the air. This more gentle air flow results in a finer stratification of particles by weight than is possible in the air columns of blowers and aspirators. To pull the light and heavy particles apart, the deck shakes back and forth and is tilted sideways to oppose the direction of the shake. The shake of the deck pushes the heavy particles up the hill while the light particles drift down the slope, floating on top of the heavier seeds and pulled down the slope by gravity. This stratification of particles by weight and separation by the use of the shake and slope continues as the seed mass works its way across the deck, giving a continuous gradation of particle weights until the heaviest are at the top, intermediate weights are in the middle, and the lightest are at the bottom. When seedlots are upgraded on gravity table, the lightest particles can be empty seeds, cone particles, straw, partially filled seeds, or even good-quality seeds that are lower in weight. The heavier particles are usually the heaviest good-quality seeds but might also be pitch, stones, dirt balls, or tramp metal that has fallen into the seeds.

Dimensional grading of seedlots before using the gravity table improves the effectiveness of the table and may even be essential. Grading should be done both by width, thickness, and, if possible, length. The more dimensional grading is done, the better the table will work. The table sorts by density or dimension but never effectively for both at the same time. For example, partially filled large-diameter seeds and same-weight seeds that are completely filled but smaller in diameter sort to the same location on the gravity table.

A final point on gravity table operation is the need for seedlots need to be clean of light trash. Otherwise a great deal of dust will be blown into the operator‘s face and create an unhealthy, unpleasant, and difficult working situation.

Upgrading quality with liquids. Fluid separations based on difference in specific gravity are another way to upgrade seeds. The separation sorts lighter seeds from heavier, but because differences in specific gravity are used, the problems of dimensional sorting are avoided. Fluid separations can be very precise separations based on weight. Water flotation, the simplest version of this, for example, can be used to remove insect-damaged acorns. The good seeds, being high in moisture content, will have specific gravities greater than 1.0 and will sink. Seeds that have been damaged significantly by insects will contain air and therefore will float (figure 38). Water can also float empty stony-coated seeds such as loblolly pine or cherries; the full seeds of these species will sink. Mixtures of hexane and chloroform have been used to separate lighter seeds from empty or partially filled seeds (Taylor and others 1982). However, phytotoxicity needs to be tested before broadly adopting fluid separation using organic solvents (Barnett 1970).

In Sweden, the fluid separation of Scots pine (*Pinus sylvestris* L.) and lodgepole pine has reached a highly sophisticated level in the processes called PREVAC ("pre-vacuum") and IDS (incubate, dry, separate) (Simak 1984; Bergsten 1993). The PREVAC system removes seeds with damaged seedcoats. The seeds are placed in water in a vacuum chamber and a vacuum is then drawn on the chamber to break the surface tension and allow the water to wet the surface of the seeds. Water will enter seeds with damaged seedcoats rapidly, increasing their weight and causing them to sink. These sinkers are discarded, for they have damaged seedcoats and will be dead. The seeds that float are drawn off the top and kept. Conducting the PREVAC procedure before IDS prevents the mechanically damaged seeds from sorting out with the good seeds in the IDS procedure.

The IDS procedure uses the fact that dead or weak seeds lose water faster than living or more vigorous seeds. In the first step, all seeds are allowed to imbibe water. With Scots pine, this is done at 15 °C for 8 to 12 days. Then the seeds are dried in super-dry air with a relative humidity ranging from 5 to 15%. The extremely rapid drying resulting from the super-dry air maximizes the difference in drying rates between viable and nonviable seeds. The living tissue in the viable seeds holds water more tightly than the nonliving tissue in the nonviable seeds. Eventually, however, the viable and nonviable seeds will both dry to the same moisture content. Meanwhile, though, samples of seeds are drawn at set intervals through the drying period and placed in water to determine the best length of time to dry. When the number of seeds floating equals the number to remove, all the seeds are placed into the water. The floaters are nonviable and are discarded; the sinkers are viable and are kept (figure 39). Unless sown immediately, the sinking seeds must be dried thoroughly to a proper storage moisture content. The process has been completely automated in Sweden using sophisticated machines. However, the basic principle can be followed using pans of water and a kitchen sieve. The key is proper incubation and very rapid rate of drying. In extremely cold climates, it is possible to simply heat ambient air to near 40 °C to achieve the desired relative humidity. However, it may be necessary to dehumidify the air further by cooling it with an air-conditioner before heating. The IDS process is protected by patent in Canada and the United States, and royalties must be paid to use the process commercially (Downie and Bergsten 1991). Successful upgrades have been reported for seedlots of Douglas-fir (Sweeney and others 1991) and *Pinus roxburghii* Sarg. (Singh and Vozzo 1990). Attempts at upgrading seedlots of white spruce, sitka spruce (*Picea sitkensis* (Bong.) Carr.), and ponderosa pine (*Pinus ponderosa* P. & C. Lawson) gave mixed results (Downie and Bergsten 1991; Downie and Wang 1992; Karrfalt 1996).

Figure 38—Chapter 3, Seed Harvesting and Conditioning: water flotation of acorns for separating good seeds from damaged seeds and trash.

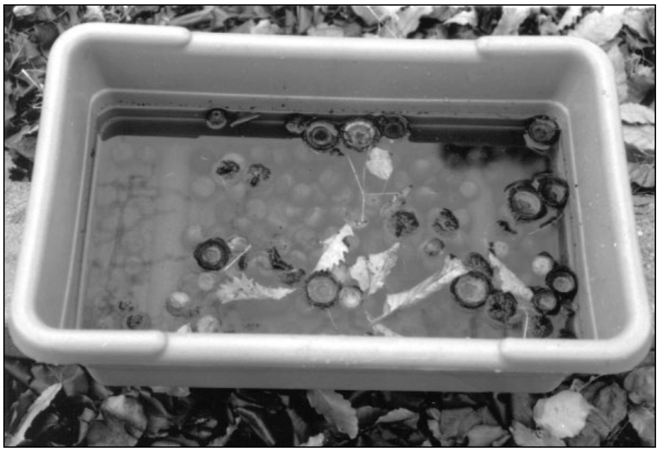


Figure 39—Chapter 3, Seed Harvesting and Conditioning: incubate-dry-separate (IDS) separation chamber; the floating seeds are discarded because of low viability and vigor, and the sinking seeds are kept because they have higher viability and vigor.

The final stage of conditioning seeds is preparation for storage, which is discussed in chapter 4. Those wishing to study further the mechanical methods and principles of seed cleaning are referred to Brandenburg (1977) and Brandenburg and Park (1977).

Conveying seeds. Moving seeds in forest seed processing plants is usually best accomplished by batch movement. In most cases, this means that a 4.5-liter (5-gallon) pail must be lifted and emptied into a hopper that feeds a conditioning machine about every 15 to 20 minutes. Larger amounts are sometimes moved with a hopper and forklift. The advantages of batch movement are greater control and flexibility of seed flow, easier clean-out, and a simpler, less expensive design. Greater control is provided because the seeds can be seen more easily for continual inspection. If the desired result is not obtained on one pass, the seeds can be immediately rerun. In continuous flow systems the seeds must flow to the next machine. Batch processing also provides greater flexibility, because the order of conditioning can be altered to match the lot and kind of seeds. In continuous flow the order of processing is relatively fixed. Bucket elevators have been used frequently in the past to move seeds, but these can be difficult to clean out. With many elevator designs, as much as 0.45 to 2.3 kg (1 to 5 lb) of seeds remain in the bottom or boot of the elevator and must be cleaned out by hand. This is much work and highly impractical with lots of less than 23.7 kg (50 lb). Because of this clean-out problem, the bucket elevator might present a major threat to lot integrity. A continuous bucket elevator (figure 40) eliminates the clean-out problem but can add to the cost of the plant. Vacuum elevators also eliminate clean-out problems but can seriously damage seeds; they move seeds very fast and sometimes stop them too quickly against hard surfaces, causing mechanical damage. Bucket elevators have also been found to damage seeds when not properly installed. The damage may not be immediately visible to the naked eye or even in a radiograph (see chapter 5). The softer the seedcoat, the easier damage can occur. Seeds of true firs would be most easily damaged; those of longleaf pine and red maple would be slightly more resistant; whereas those of ponderosa pine, loblolly pine, and dogwoods would be most resistant but still easily damaged if too much force is applied in conveying the seed. Not having elevators in the seed processing plant results in lower equipment cost, more available floor space, less noise, and lower maintenance cost.

Scooping seeds by hand must also be done with proper consideration. Even a hand scoop if thrust into the seeds too hard or rapidly will cause damage and lower viability. Seed

Table 5—Chapter 3, Seed Harvesting and Conditioning: the application and interpretation of various seed tests to seed conditioning

Test	Observation	Interpretation/action
Moisture content (MC)	Orthodox seeds	
	Above 10% MC	Dry seeds immediately to prevent deterioration
	Below 10% MC	Safe for storage; seal seeds in moisture-proof container
	Recalcitrant seeds	
	Above 25%	MC high enough to preserve viability usually
	Below 25%	Seeds likely are non-germinable
Purity	Low (trash present will clog a seeder)	Seedlot needs to be re-cleaned
Germination, tetrazolium staining, or Excised embryo	95% or better	Best quality for container seedlings & precision sowing for bareroot seedlings
	90% or better	Good quality for container & bareroot seedlings
	80%	Minimum quality for bareroot seedlings
	Below 80%	Generally more difficult to achieve good seedling densities in the nursery; to improve results, determine if empty, insect-damaged, or filled nonviable (see x-ray test below) seeds are cause for low germination
Seed weight*	High number/weight	Smaller seeds
	Low number/weight	Larger seeds
X-radiography Standard	Cracked seedcoat	Modify handling to eliminate damage
	Broken embryo	Water soak or use PREVAC to remove damaged seeds
	Empty seeds	Remove with air separators, fluid separation, &/or gravity table
	Partially filled, insect-or fungus-damaged	IDS, Dimensional grading in conjunction with specific-gravity table separation
Contrast agent	No darker (more radio-opaque) spots on image	No damage to seeds from handling
	Darker spots on image	Seeds bruised in handling; reduce number, severity, & length of drops; remove damaged seeds with IDS

* Measured in either kilograms or pounds.

Figure 40—Chapter 3, Seed Harvesting and Conditioning: continuous bucket elevator for gentle handling of seeds.

should be gently gathered onto the scoop. If time does not permit gentle scooping, then another means of conveying should be arranged.

Quality Control

Quality control is very important in conditioning seeds. Seed conditioning can be a highly complex operation, usually involving many steps and many different persons. A procedures manual is crucial, so that the role of everyone involved can be clearly identified and thought out. Writing out the steps in detail, from preparing for collection through storage and planting, provides an opportunity for a careful examination of all steps to identify potential problems and inefficiencies. Also, when procedures are fully documented, the same steps can be followed if there is a change in personnel. Many good techniques and small nuances gained through years of seed conditioning can be lost if not documented in permanent form. Typically, plant managers are not expected to publish their techniques, and knowledge is lost at retirement or job transfer. It is therefore imperative that the manager document all procedures used, in detail, either on the manager's own initiative or with the manager's supervisor. Sometimes an interview with someone who has good writing ability will help a manager get thoughts on paper.

The procedure manual should indicate all the types of records to be kept and what to do when an error occurs. Sooner or later a mistake inevitably will occur, and procedures need to be in place to handle these errors. Quality control involves more than preventing mistakes; mistakes will occur despite the best precautions. Quality control also consists of making sure that mistakes do not go undetected and that reasonable effort is made to rectify the mistake. To aid in this, records should be kept in detail showing time spent, inputs, outputs, conditions during the work, and who did the work. Who did the work is often an important factor when trying to unravel a mistake. The people who did the work will be the ones who know the most about it and have the best chance to explain what happened. A third-party review of procedures can also be of great help. Preparing to explain a process to someone else encourages a more thorough review of the work. A properly administered seed certification or seed plant accreditation program can provide this type of review.

Constantly monitoring seed quality is necessary for a high-quality conditioning operation. The specifics of testing are discussed in more detail in chapter 5. The application of the tests (table 5) is discussed here. Testing begins before harvest with cutting and x-ray tests to judge the maturity and quality of seeds. Unless it is determined that good seeds are present, a crop of totally empty or damaged seeds can be collected.

Moisture testing is critical to monitor how well we are maintaining seed moisture in all types of storage. The electronic moisture tester (figure 41) is adequate for most orthodox seeds but needs to be periodically (annually, for example) verified by a laboratory oven test. The electronic meters also must have conversion charts developed; they do not give direct readings for tree and shrub seeds. These conversion charts are made by regressing (comparing) meter readings with oven moisture tests over a range of seed moisture values. Recalcitrant seeds do not test well in electronic meters, but the procedures used to handle them should be checked at least initially to be sure moisture is kept at sufficiently high levels. This is done by drawing samples and having them tested for moisture. Otherwise, the problem might not be discovered until the seed is bought, sold, tested for germination, or, worst of all, planted in the nursery and a poor germination occurs. Following wet de-winging of conifer seeds, de-pulping of fleshy fruits, or water separation of seeds, it is necessary to dry and then test the moisture content before moving to the next step. Seeds held at high moisture even overnight could begin to respire too rapidly and begin heating. Some seeds (for example, those of longleaf pine) are shed from the cone or fruit at a high moisture content, and moisture needs to be checked and reduced if too high for safe storage.

Figure 41—Chapter 3, Seed Harvesting and Conditioning: electronic moisture testers are used to monitor seed moisture content.

Figure 42—Chapter 3, Seed Harvesting and Conditioning: radiography of pine seedlots quickly and accurately shows how many bad seeds to remove.

Visual inspection, cutting tests, and, ideally, x-radiography is used to monitor the conditioning operation. Visual inspection leads us in improving purity. Cutting tests and x-radiography reveal how many bad seeds still need to be removed. X-radiography is the better method, for it can easily show mechanical damage to the seeds, is very fast, and is more accurate than cutting tests in differentiating between good and bad seeds. If an x-ray shows that 20% of the seeds are bad and must be removed, the cleaning equipment should then be adjusted to remove 20% of the seeds by number or volume (figure 42). A second check can then be made of the seeds after the machine has been adjusted to ensure the adjustment has removed all the bad seeds it should without removing too many good seeds. The separation may not be able to be completed with one setting.

In addition to daily monitoring, the conditioning procedures need to be verified as correct by full laboratory tests, to be sure no harm is coming to the seeds and that the desired quality is achieved. Purity tests tell how much of the seed by weight is pure seed and how much is trash. A low purity value means that a better job of cleaning needs to be done. Periodically, and after any modifications of procedures, it is critical to test each step in the process for its effect on viability. Samples should be taken before and after every step in the process. X-radiography and germination tests need to be run on these samples. The x-ray will help detect mechanical damage that causes cracks in the seeds, and, if used with a contrast agent, smaller bruises on the seeds. Germination tests detect any step that stresses the seeds. Two germination tests need to be run on each sample, one on the fresh sample and one on a sample after storage. The first test will pick up the immediate problem areas. The test after storage will be more effective in detecting latent damage. Some damage is not immediately obvious in the germination test but requires time for deterioration to develop to the point at which a drop in germination can be measured.

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