Chapter 4
Seed Management

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Abstract

Proper seed management is crucial to southern pine regeneration programs. Almost all seeds will soon be collected from the more than 4,000 ha of seed orchards, where production rates are now about 100 kg/ha for older orchards. Orchard collections can be either multiclone bulk or separate clonal, depending on management objectives. Collection of cones by hand from hydraulic lifts is still the most common technique, but net retrieval systems are used increasingly for loblolly (*Pinus taeda* L.). New extraction and cleaning systems can produce extremely good seedlots. The most common plant sequence is: (1) scalping of large debris, (2) dewinging, (3) cleaning, and (4) sizing and other conditioning steps. Cleaned lots should be sampled correctly for tests of moisture, purity, weight, and germination. Standard laboratory germination tests are still best, but sound information on seed quality is available from certain rapid tests, such as the measurement of leachate conductivity. Prechill treatments for dormant lots vary by species and sowing environment, but 30 to 60 days is most common for loblolly. If paired tests show extensive dormancy, 60 to 90 days may be best. If tests show low seed vigor, prechill length should be decreased to 20 to 30 days. Southern pines are considered "orthodox" in storage behavior. Seed moisture contents below 10% and temperatures of 2°C are sufficient for storage of 2 to 3 years. For longer storage, -18°C is best.

4.1 Introduction

The cornerstone of a successful regeneration program for southern pines — whether for natural or artificial regeneration — is a good seed supply. But it has been the initiatives for tree improvement and plantation culture of southern pines that have focused attention on the value of good seed quality. The investments required for tree improvement programs ($10 to $15/ha, or $4 to $6/ac, of plantation [71]) have demanded maximum seed efficiency and led to many innovations in seed handling and management in the last 20 years.

This chapter reviews state-of-the-art information on seed technology of southern pines and how it can be applied for good seed management. The primary species considered are eastern white pine (*Pinus strobus* L.),[1] loblolly pine (*P. taeda* L.), longleaf pine (*P. palustris* Mill.), sand pine [*P. clausa* (Chapm. ex Engelm.) Vasey ex Sarg.], shortleaf pine (*P. echinata* Mill.), slash pine (*P. elliottii* Engelm.), and Virginia pine (*P. virginiana* Mill.). Other species included where information is available are pitch pine (*P. rigida* Mill.), pond pine (*P. serotina* Michx.), and spruce pine (*P. glabra* Walt.).

4.2 Seed Acquisition

Acquisition of southern pine seeds has shifted dramatically in the last 10 years from natural stands, plantations, or seed production areas to seed orchards of selected material. Of the 1.5 billion southern pine seedlings planted in the United States in 1984, over half were from genetically improved seeds [94]. This percentage increases each year as seed orchard production increases, even though natural stands still furnish a significant proportion of the total southern pine seed supply. With the jump in seed demand spurred by the Cropland Retirement Program in 1986-87, however, both natural stands and seed orchards will continue to be important over at least the next 5 years. Regardless of the producer, the proper geographic sources should be utilized in regeneration programs to match species and genotype to site (see chapter 11, this volume). A recent summary of seed-source information [82] is an excellent guide for these decisions.

4.2.1 Seed Orchards

There are over 4,000 ha (10,000 ac) of southern pine seed orchards, with loblolly and slash representing 85% of the total (Table 4.1). Most of these orchards are currently producing seeds, and considering orchard age, production should continue to increase for many more years. Tree improvement programs are expensive, but if a managed land base of 60,000 to 80,000 ha (150,000 to 200,000 ac) or

[1] Although not truly a "southern pine," eastern white pine is an important species in the South and therefore is included here.

M.L. Duryea & P.M. Dougherty (eds), Forest Regeneration Manual, pp. 51–73.

Table 4.1. Area of southern pine seed orchards, 1981 [117].

Pine species	Area	
	Hectares	Acres
Eastern white	44	108
Loblolly	2,219	5,482
Longleaf	179	443
Pitch	4	9
Pond	19	47
Sand		
Ocala	17	43
Choctawhatchee	14	34
Shortleaf	231	572
Slash	1,275	3,151
Spruce	0	0
Virginia	95	235
Total	4,097	10,124

more is available, the programs should be good investments [71]. Even small companies or individual landowners who cannot afford to establish their own seed orchards can reap the same benefits by buying improved seeds or seedlings. And as production of southern orchards increases, this material becomes more accessible.

4.2.1.1 Management

Although this chapter cannot provide complete details on establishing and managing seed orchards [see 45, 50, 63, and 129 for details], some management aspects important to seed production deserve mention. Cultural practices in younger orchards are designed to stimulate tree growth and vigor, in older orchards to stimulate flowering and seed production. For most species, fertilization and irrigation before flower initiation have increased cone production [66, 102, 129]. Suggested annual fertilizer levels for loblolly pine are 400 kg/ha (357 lb/ac) of nitrogen, 80 kg/ha (71 lb/ac) of potassium, 40 kg/ha (36 lb/ac) of phosphorus, and 50 kg/ha (45 lb/ac) of magnesium [129]. In one orchard, high levels of nitrogen fertilization did not benefit longleaf seed production, and more research may be needed on this species [61]. Drip irrigation has proved effective in many orchards [106]. Subsoiling around trees also stimulates cone production [129].

Insect control is very important in seed orchards. Cone and seed losses can be extremely high from such pests as the Nantucket pine tip moth *(Rhyacionia frustrana)*, pine coneworms *(Dioryctria* spp.), pine seedworms *(Laspeyresia* spp.), pine seedbugs *(Leptoglossus corculus; Tetyra bipunctata)*, and seed chalcid *(Megastigmus atedius)*. Information on life cycles, damage identification, and relative importance of these insects has been summarized [53, 69; see also chapter 20, this volume]. Annual control measures can cost almost $500/ha ($200/ac), depending on the insecticides used, application frequency, and other factors, but potential insect losses of one-half to two-thirds of the crop make this a wise investment [58].

Several good insecticides are currently registered for orchard application. Because label approvals and state regulations may change frequently, orchard managers should check with state and federal extension personnel or U.S.D.A. Forest Service pest-management specialists for current guidelines.

Pitch canker *(Fusarium moniliforme* var. *subglutinans)*, a serious problem in orchards from North Carolina to Texas [52], can cause conelets to abort, maturing cones to die, and some seed to deteriorate within cones. Infection is through wounds caused by tree-shaker bole damage, pruning, mowing, and limb breakage from hand-picking cones. Minimizing these types of damage can reduce infection.

4.2.1.2 Production

Average cone and seed data frequently cited for the southern pines are based primarily on collections from natural stands (Table 4.2). Cones and seeds from well-managed orchards are usually larger that those from natural stands. Yield of seeds extracted from cones from U.S.D.A. Forest Service orchards 15 to 20 years old has been as high as 98, 86, and 24 kg/ha (87, 77, and 21 lb/ac) for loblolly, slash, and eastern white pines, respectively [91]. Yield of seeds collected directly from nets (see 4.3.2) has generally been lower in these orchards, but other orchards have produced up to 100 kg/ha (89 lb/ac) with net collection

Table 4.2. Average cone and seed data for southern pines (adapted from [4, 9, 79]).

Pine species	No. of seeds/cone		No. of seeds by weight		No. of cones by volume	
	Potential	Average yield	Per kilogram	Per pound	Per hectoliter	Per bushel
Eastern white	–	58	38,600–116,900	17,500–53,000	1,400	500
Loblolly	150–155	36	27,100– 58,200	12,300–26,400	1,400	500
Longleaf	157	49	6,600– 15,400	3,000– 7,000	300	100
Pitch	–	40	93,700–181,300	42,500–82,200	4,500	1,600
Pond	–	34	103,600–138,900	47,000–63,000	4,500	1,600
Sand						
Ocala	–	57	57,300–149,500	26,000–67,800	2,300	800
Choctawhatchee	–	56	90,000–129,900	40,800–58,900	2,900	1,000
Shortleaf	87–96	23	70,800–160,700	32,100–72,900	5,700	2,000
Slash	170–175	68	21,200– 42,600	9,600–19,300	600	200
Spruce	–	23	88,200–114,700	40,000–52,000	5,700	2,000
Virginia	84–88	33	100,800–200,900	45,700–91,100	4,800	1,700

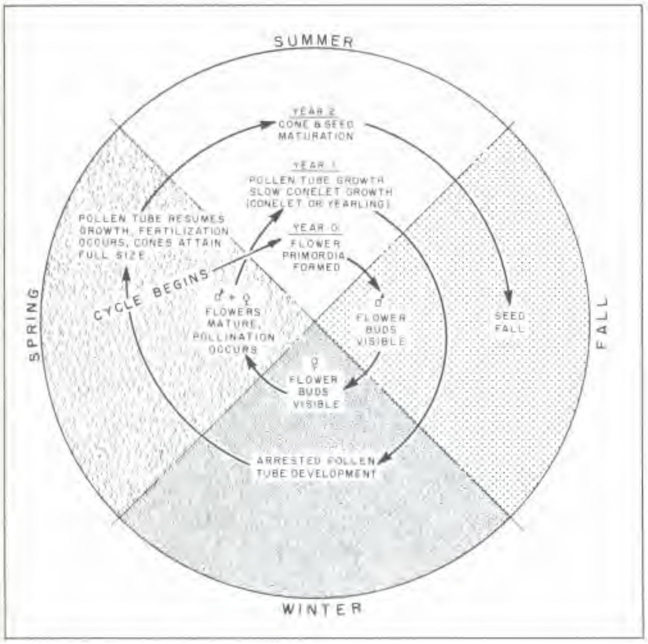


Figure 4.1. Diagrammatic reproductive cycle of flowering and seed maturation in southern pines [44].

[119]. Maximum yields probably have still not been reached. When orchards are thinned through roguing, production increases usually appear 3 to 4 years later [100, 129]. Assuming that a kilogram of seed should produce 17,000 plantable seedlings, a hectare of orchard yielding 50 kg should produce enough seeds annually to plant about 600 ha. [One pound should produce 8,000 plantable seedlings, and 1 ac of orchard yielding 45 lb should produce the seeds to plant about 640 ac.]

4.2.2 Natural Stands

When cones are collected from natural stands, the same general guidelines apply for all species:

(1) Collect from (a) geographic sources known to be suited to the sites to be planted, or (b) local sources.
(2) Collect from the best phenotypes.
(3) Avoid isolated trees (pollination may have been poor).
(4) Make sure cones are fully or nearly mature when picked.

Most natural-stand collections are made from tops following harvest, so only guidelines (lb) and (3) can be fully observed. Moreover, most are made by individuals who sell the cones to seed dealers or state forestry organizations. Cone buyers should be careful to avoid buying immature cones, year-old cones, or cones from the wrong geographic sources.

4.2.3 Factors Affecting Cone Production

Although fecundity is largely an inherited trait, environmental factors can significantly alter flower and cone production. The influence of environment is complex, and many research studies have produced inconclusive or conflicting results. A recent comprehensive review of forest-tree seed production [102] concluded that flower initiation is generally favored by high light intensity and temperatures, low rainfall and soil moisture, and high soil fertility just before bud determination. Flower production can be enhanced by cultural treatment in seed orchards (see 4.2.1.1), and treatment with growth regulators has shown promising results, primarily with western conifers [102].

Pollination is perhaps the most vulnerable step in the reproductive cycle (Figure 4.1), and conditions that decrease pollination can seriously reduce the seed crop. Late-spring freezes can kill flowers and pollen grains. Excessive rains when pollen is shed can also significantly reduce seed set [80]. In young orchards, extra pollen may be required for good seed production. Broadcast application of pollen within orchards, commonly called supplemental mass pollination, has been used successfully in southern pine orchards to increase seed set [102]. Details of pollen application and other aspects of pollen management can be found in the *Pollen Management Handbook [118].*

Post-pollination conelet loss, common in pine, is usually related to inadequate pollination. Post-fertilization cone loss is not common [102], except for losses caused by insects [53]. In the final year of the reproductive cycle, seed maturation can also be influenced by the environment. Severe drought from midsummer to late summer may reduce the size of mature seeds; however, effects during the maturation period are small compared to those during pollination and fertilization.

4.2.4 Estimating the Seed Crop

Precollection inspections are always important for estimating potential seed crops, especially from natural stands. Managers may judge crop prospects a year in advance by counting first-year cones; they should also count cones in the year of collection. Midsummer counts with binoculars on only 4 to 5% of the trees in a Virginia loblolly orchard gave good crop estimates [126]. A two-person counting system proved successful in a 40-year-old shortleaf seed-production area [107]. Cones should also be cut open lengthwise in late summer for counts of filled seeds in the exposed cross sections; these counts can be related to average seed/cone yields through conversion factors developed with cones from natural stands (Table 4.3). Whether orchard cones have this same conversion ratio is not known. Other data on cone and seed yields are also helpful in calculating collection needs and expected yields (Table 4.2).

4.2.5 Purchasing Seed

Large quantities of southern pine seeds from natural stands have long been available for purchase. In the mid-1980s, bumper crops in many seed orchards put some of these seeds on both domestic and international markets. For their own protection, buyers should always insist on:

(1) A contract stating species, geographic source, mini-

Table 4.3. Seed yield/cone for four southern pine species growing in four states, as estimated from number of seeds exposed when cones are bisected longitudinally [48].

Average number of sound seeds exposed	Total number of sound seeds/cone				
	Longleaf (Louisiana)	Loblolly (Louisiana)	Slash (Louisiana)	Slash (Georgia-Florida)	Shortleaf (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

mum germination and purity, maximum moisture content, and price.

(2) A germination test (or other evaluation of seed quality) by a third-party laboratory.

Contract prices can be set on a sliding scale, the price decreasing from maximum for each incremental decrease in quality as determined by the testing laboratory. Or prices may be set according to the number of pure live seed per kilogram ("pure live seed" concept), the price based on purity, germination, and seed weight as determined by the laboratory. This procedure, which deserves more attention, avoids problems caused by different seed sizes and moisture contents, as well as varying amounts of filled dead seeds.

The laboratory tests required in seed sales should be completed within 6 months of the sale date. Test procedures prescribed by the Association of Official Seed Analysts (AOSA) [2] should be specified in the contract. Third-party testing is available at the U.S.D.A. Forest Service's National Tree Seed Laboratory in Macon, Georgia, and from several commercial seed laboratories in the South. State seed-testing laboratories are members of AOSA and can test tree seeds, but most are reluctant to do so because they are not familiar with the species.

In each state having labeling laws for tree seeds (see 4.5.5), inaccurate information on labels should be reported to the state's agricultural department. Penalties for inaccurate information vary among states, but reporting could improve the buyer's legal position if problems with the seeds are discovered later.

4.2.6 Certification

Buyer protection in seed transactions is improved with seed certification, a voluntary program in which seed or seedling producers pay a certifying agency in their state to inspect their crop and certify to buyers that the genetic identity and quality level claimed are accurate. This information is printed on special tags that certifying agencies attach to seed containers. Although certification standards differ slightly among the southern states, most recognize three levels of certification (identified by their tag colors):

(1) *Yellow tag:* Seeds whose geographic source only is certified; no genetic superiority is claimed but may be implied (for example, fusiform rust resistance of Livingston Parish, Louisiana, loblolly).

(2) *Green tag:* Seeds from selected trees (usually in a seed orchard) that promise genetic superiority not yet demonstrated (progeny tests not complete).

(3) *Blue tag:* Seeds of demonstrated genetic superiority; orchard seeds whose progeny tests have demonstrated performance in one or more traits above a minimum level designated by certification standards.

Certification as standard procedure is relatively new, although the State of Georgia has had certified seeds and seedlings since the 1960s. However, as more and more orchard seeds are sold commercially, the demand for certification has increased. Foreign buyers, in particular, want assurance through certification; some may require OECD (Organization of Economic Cooperation and Development) certification, an international program established in Europe, and now used by many non-European countries as a means of buyer protection. Certification standards of the southern states generally exceed those of OECD; thus, compliance should not be a problem. For information on certification programs, seed managers should contact their state extension service, land-grant university, state agriculture agency, or the National Tree Seed Laboratory.

4.3 Cone and Seed Collection

Until recently, all pine seeds were collected by shaking or picking cones from trees or logging slash, then extracting the seeds from the cones. This system has two major weaknesses: (1) high cost of hand picking in orchards as trees grow beyond the reach of most hydraulic lifts, and (2) high potential for damage to seeds during extraction and dewinging. Both weaknesses can be minimized by catching naturally disseminated seeds on plastic mesh net spread on the orchard ground; use of this net retrieval system (see 4.3.2) is increasing, but most seeds are still obtained from collected cones.

4.3.1 Cones

Ideally, cones should not be picked until seeds are fully mature. Immature seeds are likely to have low vigor and to yield smaller seedlings that are more susceptible to stress and pathogens [114]. The size of most collection operations, however, is too great to allow the biologically ideal situation. The common practice is to start collecting cones before they are fully mature and store them so that seeds mature during cone storage. A key factor, of course, is recognizing the stages of cone and seed maturity. Unfortunately, the approximate dates of cone ripening (Table 4.4) are too general for collection guidelines.

Table 4.4. Phenology of cone maturation and seed dispersal (adapted from [12, 19, 79, 84]).

Pine species	Approximate cone-ripening dates	Seed dispersal begins[1]
Eastern white	August-September	August
Loblolly	September-October	October
Longleaf	September-October	October
Pitch	September	–[2]
Pond	September	–[2]
Sand		
Ocala	September	–[2]
Choctawhatchee	September	September[3]
Shortleaf	October-November	October
Slash	September-October	September
Spruce	October	October
Virginia	September-November	October

[1] Completion of dispersal varies widely depending on weather. Loblolly and shortleaf will retain some viable seeds for up to 1 year.
[2] Serotinous cones; seeds can be retained 3 to 4 years.
[3] Most cones open the fall of maturity; some are "semi-serotinous."

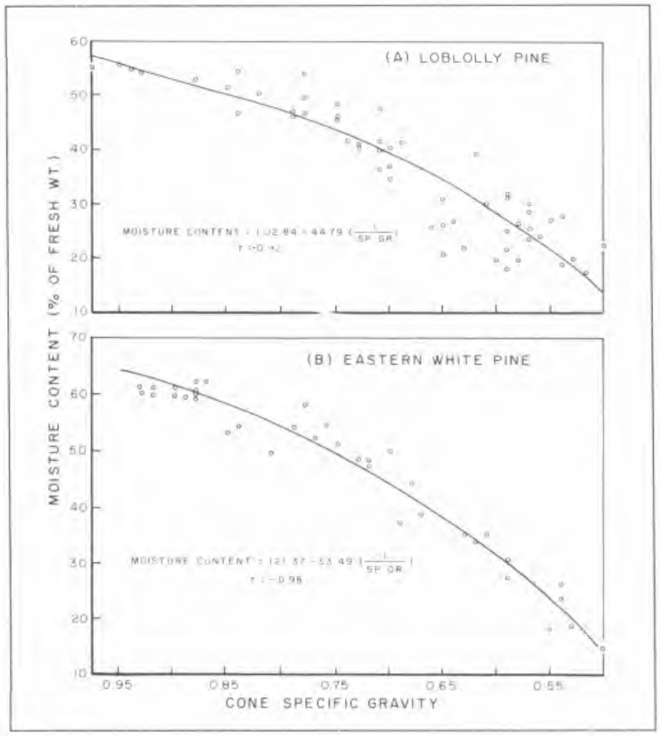


Figure 4.2. Relationship of cone specific gravity to cone moisture content for loblolly (A) and eastern white (B) pines [30, 34].

4.3.1.1 Determining cone maturity

In the South, decisions about cone maturity have long been based on specific-gravity guidelines developed by Wakeley [124]. He recommended picking cones when their specific gravities fell below 0.89, which was determined by a cone's flotation in SAE20 oil. Flotation should be done within 10 minutes of picking cones to avoid excessive moisture loss [124]; collection can proceed when fresh cones from 19 of 20 trees float. Later experience showed that cones with specific gravities of up to 1.0 could be successfully collected if they were handled and stored carefully before seed extraction (see 4.4.1). Therefore, any cone that floats in water can be collected. Eastern white pine is a possible exception. At cone specific gravities above 0.90, cone moisture contents of this species are above 60%, a level that demands very careful handling to avoid damage [30]. It is best to delay collection of eastern white pine cones until they are a "straw yellow" color [88]. Collection of serotinous cones, such as those of Ocala sand pine (var. *clausa),* can be delayed even longer; these cones can be collected after they have turned completely brown, because they do not open on the trees [12].

The crucial factor, of course, is not specific gravity, but cone moisture content. Measuring specific gravity by flotation is just the quickest way to estimate cone moisture. The relationship between cone moisture content and specific gravity is seen in Figure 4.2 for loblolly and eastern white pines. For precise measurement, cone specific gravity can be determined with an easy procedure based on cone immersion in water [9].

Although flotation in water should be the key index for cone collection, seed appearance should also be checked to confirm decisions to collect. Mature pine seed embryos and gametophyte tissues should be firm and white to cream or yellow. Despite biochemical studies of maturation in southern pine seeds [7], biochemical indexes of maturity have not been developed to the extent that they have for some western conifers [112]. Climate, topography, and species characteristics combine to make cone collection relatively easy in the South, and biochemical indexes are not helpful.

Orchard managers of today should be familiar with the sequence and approximate dates of ripening of all of their clones. The time between ripening dates of the earliest and latest clones in one South Carolina loblolly orchard was 50 days [130]. However, maturity checks by water flotation of cones are still essential, because clonal maturity dates can also vary slightly between years [50].

4.3.1.2 Clonal vs. bulk collections

Recently, some industrial operations have collected orchard cones separately by clone and maintained clonal identity through seed extraction, seedling production, and outplanting to enhance genetic gain by matching families or family groups to particular planting-site conditions [64]. Once clonal cone-ripening sequence is known in the orchard, actual collection should cost little more than bulk collection from the same trees. The major additional expenses of clonal collection lie in the nursery and outplanting phases. Producers who use it, however, believe that the extra cost is more than offset by a gain in volume growth from better seedling-site relationships. Others maintain that broader genetic bases are important in plantations, and that clonal collections are neither necessary nor desirable. The few published results on this issue [101] indicate that more study is needed (see chapter 11, this volume).

4.3.1.3 Collection methods

Cones of longleaf and slash pines are usually removed from trees by mechanical shakers. Some shakers are self-propelled units; others operate from a tractor's power take-off (PTO). Good shaker operation should remove 80% or more of longleaf or slash cones [55]. One time trial with slash pine showed that a shaking rate of 40 trees/hour was possible [108].

The major concern with shaker use in seed orchards is to avoid damage to the trees. A study in Louisiana found no effect of proper shaking on cone production or growth of slash pine for at least 4 years [98]. However, excessive shaking can break off branch tips and first-year cones and damage boles where shaker clamps are attached. Wounds on the boles are prime infection sites for pitch canker *(Fusarium moniliforme* var. *subglutinans)* [52]. Rubber pads on the clamps can help minimize this damage.

Cones of other southern pine species will not fall off when shaken and must be picked by hand unless seeds are collected in nets (see 4.3.2). Climbing trees and using ladders are no longer practical because of tree size, so cones are now gathered from hydraulic lifts ("cherry pickers"). One production estimate is that 9 hydraulic bucket trucks and 14 men are required to harvest 40 ha (100 ac) of loblolly orchard in 20 days, assuming a "good" cone crop [55]. However, collection by hydraulic lift has two major disadvantages: (1) lifts are expensive to own, although leasing is common, and (2) trees in the older loblolly orchards have grown out of reach of the typical lifts. Costs for hand-picking cones from hydraulic bucket trucks with Forest Service labor in 1983-84 were estimated at $85/hL ($30/bu) [93]; costs may be lower when the job is contracted with independent collectors.

Although shrinking in importance each year, collecting from natural stands still occurs. Almost 2 hL (5 bu) of loblolly cones per person-day is not unreasonable production when picking in logging slash. Because determining cone maturity in logging slash is difficult because of rapid cone drying, cone buyers must be alert for immature cones.

4.3.2 Net Collection of Seeds

An alternative to collecting cones by hand is the net retrieval system (NRS). Originated by the Georgia Forestry Commission in the early 1970s [128], NRS is now used in southern orchards to collect loblolly, Virginia, and eastern white pine seeds. Polypropylene netting (actually carpet backing) is spread on the orchard ground before cone opening. As cones open naturally (see Table 4.4), seeds fall to the netting, often aided by slight mechanical shaking. When most of the seed crop is judged to be on the netting (usually late December of January), it is rolled up and the seed recovered.

Advantages of NRS are:

(1) Judgments of cone maturity are unnecessary.
(2) Purchase or lease of hydraulic bucket trucks is unnecessary.
(3) Potential damage to seeds from extraction and dewinging is avoided.
(4) In good crop years, collection costs per kilogram (pound) of seed are lower than those of picking cones by hand [93].

Disadvantages of NRS are:

(1) Seeds on the netting are exposed to predators and unfavorable environmental conditions (moisture contents are usually high at retrieval).
(2) Specialized equipment may have to be purchased.
(3) In poor crop years, collection costs per kilogram (pound) of seed are higher than those of picking cones by hand [93].
(4) Collecting by individual clone is not possible.
(5) Some clones disperse seeds too slowly.
(6) Complete separation of seeds from debris is difficult.

4.3.2.1 Equipment and procedure

The polypropylene netting comes in rolls 5 m (16.5 ft) wide and approximately 180 m (600 ft) long. For seed-orchard use, the cardboard cores should be removed and replaced with aluminum irrigation pipe 10 cm (4 in.) in diameter and 5.3 m (17 ft 3 in.) long [92]. The netting can be unrolled in the orchard with tractors or trucks; ends and sides are then stapled together up to the base of the trees. Experience has shown that if the rolls of netting, when not in use, are stored out of direct sunlight, they should last more than 10 years.

Netting can be retrieved and seeds recovered in several ways. U.S.D.A. Forest Service engineers have developed tractor-drawn retrieval equipment that runs on < 30 PTO horsepower [92]; this equipment rolls up netting on the aluminum-pipe cores, dumping seeds and other debris into a cleaner that removes the bulk of the unwanted material (Fig. 4.3). One retrieval machine and five or six workers can easily harvest 16 to 24 ha (40 to 60 ac) of orchard [92]. Details on sources of equipment and cost estimates are available [55, 92, 93].

Another retrieval system uses tractors to pull the sections of netting to the end of the orchard compartment, placing seeds and debris in a "windrow" on a piece of netting. A modified peanut combine is then pulled over the "windrow" to remove most of the debris. The seeds, still on the netting, are transferred to containers [128].

4.3.2.2 Seed handling

The high seed moisture contents that are normal at retrieval can be troublesome. Cleaning at the orchard still leaves a considerable amount of small, moist debris that must be dry before it can be removed efficiently. To avoid loss of seed quality, each day's collection should be either

Figure 4.3. Net retrieval system equipment developed by the U.S.D.A. Forest Service for collection in southern pine seed orchards.

(1) spread indoors in a thin layer to dry, or (2) placed in cold storage (above freezing) temporarily to prevent possible heat buildup until it can be dried and cleaned. With proper care, quality can be maintained in loblolly pine seed for use immediately or after at least 1.5 years of storage [39].

Seed losses to birds and rodents can be a serious problem, particularly if the predators have good cover close to or even within the orchard. Losses to predators from NRS plots at four U.S.D.A. Forest Service orchards in 1983-84 ranged from 18 to 78% [122]. Losses always seem heaviest after December, probably when alternate food supplies run low. Therefore, retrieval before January is recommended, even though recalcitrant clones may still have as many as 95% of seeds in their cones [41]. Orchard managers should identify such clones and pick their cones by hand to assure that all families in the orchard are utilized.

4.4 Seed Extraction and Processing

A major phase of seed management is the extraction of seeds from cones and the processing of seeds to put them in optimum condition for use. It is a crucial phase in that most human-caused damage to pine seed quality occurs at this point. The dangers are much less for seeds collected from netting because they do not require extraction and dewinging. They do, however, require drying, cleaning, and conditioning (Fig. 4.4).

4.4.1 Cone Storage

Cones of the southern pines are usually stored briefly before extraction. In addition to simply holding cones until they can be extracted, storage serves two useful functions: (1) loss of cone moisture during storage reduces energy requirements for kiln drying, and (2) cones picked while still immature undergo a certain amount of ripening during storage.

Green cones may have moisture contents of 60% or higher when picked. Extraction studies [22, 29] have shown that cone moisture should be between 35 and 50% before kiln heat is applied, and that complete cone opening occurs when they are dried to about 10%; gradually drying cones to 25% moisture during storage may impair cone opening and damage seed quality [29]. However, proper storage (often called "precuring") can reduce the amount of moisture to be removed in the kiln by as much as two-thirds [29], providing significant savings in fuel costs. One good rule-of-thumb for loblolly is that when a bushel of cones weighs 25 lb (11.2 kg), it is ready for the kiln.

Several studies have shown that cone storage for 3 to 5 weeks is beneficial to seed yield and quality of slash and loblolly pines [7, 34, 95]. McLemore [95] and Bonner [33] concluded that the same was true for longleaf, but Barnett [7] found storage damaging to immature longleaf seeds. These differences are probably related to cone maturity when cones were picked and first stored. Prior to some thresholds, seeds in immature cones will not mature during cone storage. For species with "sensitive" seeds, such as longleaf or eastern white pine, cone storage should be held to a minimum to avoid damage; about 1 week seems to be the maximum for eastern white pine [30]. Shortleaf and Virginia pine cones appear to lose moisture much like loblolly cones [29], so 3 to 5 weeks of storage also is recommended for them. Other work on Virginia pine in the northern portion of its range [59] supports this recommendation.

Many studies have been carried out on "artificial ripening" of cones of southern pines picked as early as 2 months before cone opening [81]. Few, if any, collections are made that early today because yields are generally reduced [81]. In contrast, current cone-storage practices usually improve yields.

Most cones are stored in 7-hL (20-bu) wire-bound boxes (Fig. 4.5) or in burlap bags; both of these container types are satisfactory for storage if cones are properly handled [10, 34, 46]. No more than 0.33 hL (1 bu) of green cones should be put in each bag to allow room for cones to expand as they open. Outdoor storage, common in the South, usually promotes maximum cone opening, apparently through the naturally alternating wet and dry conditions [30, 33, 34]. If rain is lacking, stored cones should be thoroughly wetted at least once a week. Cones in the center of 7-hL (20-bu) boxes will often become moldy on the outside; however, seed quality of loblolly and slash pines is usually not harmed [34]. If immature cones "case-harden" and fail to open when dried, they should be thoroughly wetted and redried several times. After each wet/redry cycle, the scales will open more than the previous time.

4.4.2 Seed Extraction

Extraction of seeds from cones requires (1) drying to open cone scales and (2) mechanical tumbling to shake

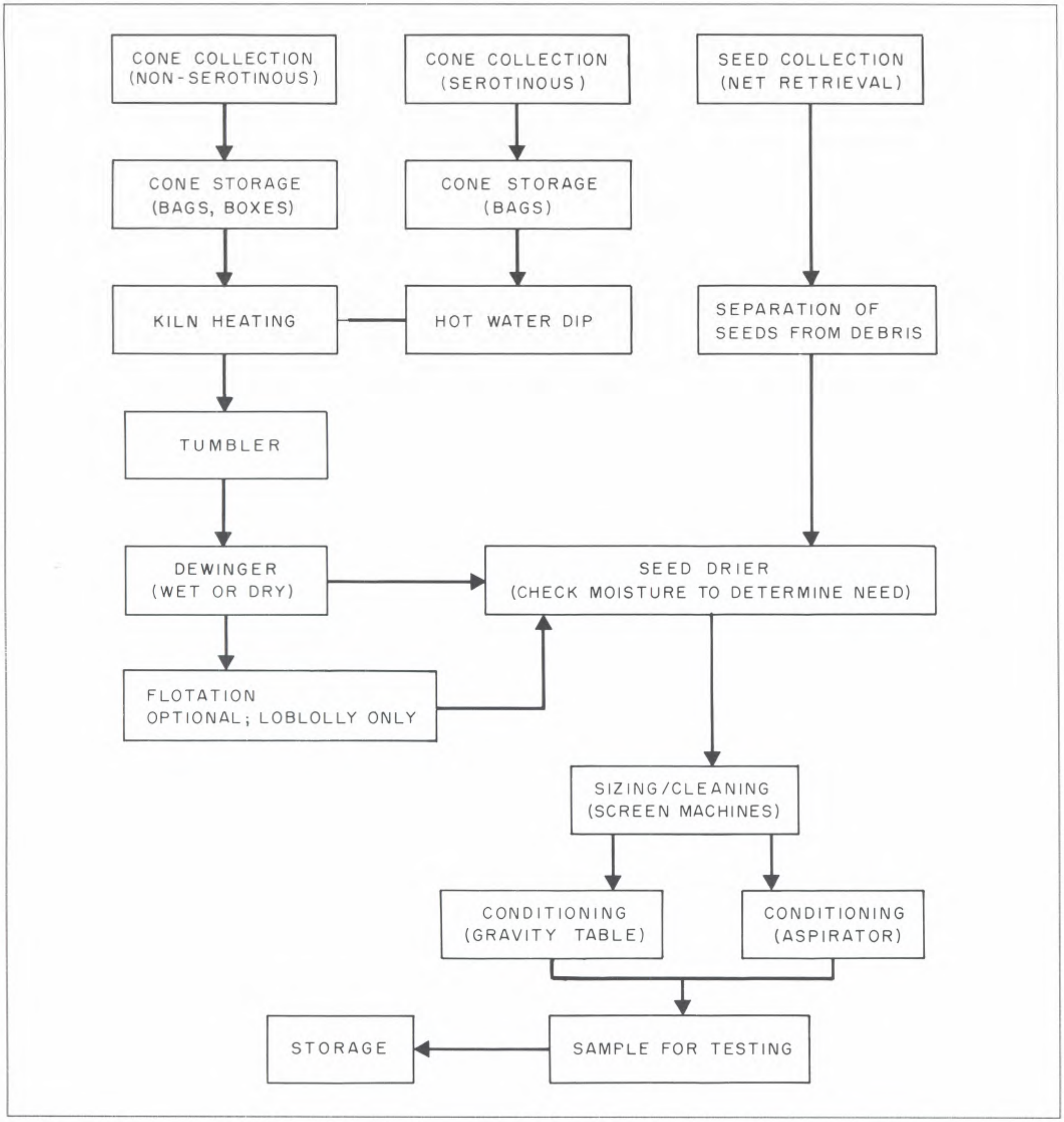


Figure 4.4. Flow chart of typical extraction and processing of southern pine seeds. Local applications may vary.

seeds from open cones. These two operations are usually performed in two stages but can be done simultaneously.

4.4.2.1 Kiln drying

Three major types of kiln systems are available for southern pines: **(1)** rotating tumbler driers, (2) progressive kilns, and (3) tray kilns. Rotating tumbler driers are large heated drums that turn slowly and tumble cones as they dry. Modern kilns of this type can be programmed for the desired temperature and relative humidity **(RH).** Rotating kilns are primarily used for batch processing, a requirement if clonal lots are kept separate; they are also effective for hard-to-open cones. Progressive kilns are long heated chambers in which stacked trays of cones [0.7- or 1.4-hL (2- to 4-bu) tray capacity] are moved from one end to the other at planned time intervals. There is no mixing of

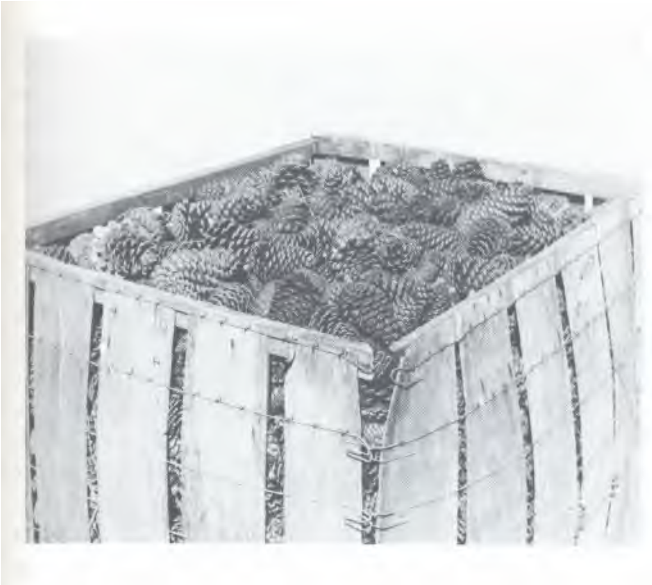


Figure 4.5. Wire-bound boxes commonly used for pine cone storage. Each one holds 7 III (20 bu) of green cones.

Figure 4.6. Tray extraction system for drying pine cones.

material between trays. Kiln temperatures increase toward the exit end, which places only the driest cones at the highest temperature. Modern progressive kilns can also be programmed for temperature and RH. Popular on the West Coast, these kilns can be used for both large- or small-batch processing.

The most widely used system in southern pine extractories is the tray system (Fig. 4.6). Trays are typically 1.2 x 2.4 m (4 x 8 ft) and 40 cm (16 in.) high, with galvanized wire mesh in the bottom. They are stacked six high; a standard "unit" is 48 trays in 8 stacks of 6 each. With 2.1 hL (6 bu) of cones per tray, single-load capacity is about 100 hL (288 bu). Such a unit should be able to process about 3,500 hL (10,000 bu) of cones in a 10- to 12-week period [72]. Heated air is blown into the bottom and up through the stack to dry the cones. Humidity can be controlled, and heated air can be recirculated to save fuel. This system is good for both large- and small-batch processing.

Several plants use a modified tray system, in which cones are dried in peanut drying wagons. The wheeled, metal wagons are altered to support five wire-mesh trays that hold 7 hL (20 bu) of green cones each. Heated air is blown upward through the trays, but not recirculated. One heater/blower unit can dry two wagons at once. One plant can easily dry 1,700 hL (5,000 bu) or more per year with five wagons and two heater/blowers [77].

Several kilns have been designed to handle small batches of progeny test cones or other special collections of 0.33 to 0.67 hL (1 to 2 bu) each. Specifications and plans are available for many of these [26, 87, 90, 116]. A few solar kilns have also been built [19], but their capacities are low and their efficiencies unknown.

With the exception of eastern white pine, cones must be dried to about 10% moisture content for complete opening [22]. Common kiln temperatures range from 32 to 46°C (90 to 115°F). However, the optimum temperature depends on initial cone moisture content, RH, kiln load, and perhaps clonal characteristics. Initial kiln temperatures should be low (30 to 35°C) if cone moisture is 50% or higher; at this moisture level, temperatures above 35°C will damage seeds. As cones dry to moisture contents of 40 to 45%, temperatures can be increased to the maximum [29]. If cones are dried too quickly, they do not open well.

Longleaf and eastern white pines are very sensitive to heat, and even with low cone moisture, they should be dried with caution at 35 to 38°C (95 to 100°F). In fact, eastern white pine will open at 35% RH at any temperature [19]. Excessive heat will increase the release of resin from cones of eastern white pine, which may cause the seeds to stick together. If this happens, seeds can be placed in cold storage until the resin hardens, then removed for cleaning or dewinging. The hardened resin will break up easily into a white "dust."

Orderly and successful extraction operations require a certain sequence based on species characteristics. Species that are more sensitive to damage during cone storage should be extracted first. Based on general ripening dates [12, 19, 79], the usual order of collection is eastern white, slash and sand (Choctawhatchee race, var. *immuginata),* longleaf and Virginia, and loblolly, shortleaf, and spruce pines. Species with serotinous cones — pitch, pond, and sand (Ocala race) — can be collected after all others because their cones remain closed for months or even years. The usual order of extraction would be eastern white pine, slash, longleaf, Virginia, loblolly, and shortleaf. Longleaf is the most sensitive, and extraction of slash seeds may have to be interrupted to process longleaf cones. Longleaf cones should not be stored more than 3 to 5 weeks before extraction. In warm, moist weather, longleaf seeds will germinate while still in the cones. Because cones of the other species can be stored for longer periods, their extraction should be delayed until that of longleaf is completed.

If seed yields are poor because many cones have not opened in the kilns, a second cycle through the kiln may be profitable. Karrfalt [75] has suggested a procedure to help processors decide if a second extraction is worthwhile. Cones should be soaked in or sprayed with water to promote closure, then put back into the kiln for drying; in modem programmable kilns, cones can be closed with added moisture and then redried without ever removing them from the kiln. Seeds from the second extraction are usually of lower quality [75], but their recovery may be desirable for valuable lots.

4.4.2.2 Serotinous cones

Serotinous cones require special treatment to disrupt the resin bonds that prevent opening of the scales. A 15-second dip in boiling water will break the resin on cones of Ocala sand pine. The cones can then be fully opened in kilns by drying for 24 hours at 38 to 43°C (100 to 110°F). If serotinous cones are partially open, the dip in boiling water may damage the seeds [19]. In such cases, cones should be sprayed with cool water to close the scales before being dipped in boiling water.

4.4.2.3 Cone tumbling

Once cones are open, mechanical tumbling devices shake the seeds out. In rotating kilns, tumbling takes place in the kiln as cones dry. In all tumblers, seeds fall through perforated cylinders and are removed from the bottom of the drum. Tumblers are usually inclined so that seeds flow to one end, and most contain baffles that increase the tumbling action of the cones [112]. Several tumblers have been constructed for small lots of 0.2 to 1.8 hL (0.5 to 5 bu) [26, 60, 68, 85, 127], and many are homemade devices — large drums or cylinders that rotate on a central axis.

4.4.3 Seed Cleaning and Conditioning

Once seeds have been removed from cones, processing becomes easier. The bulk of material to be handled is much less, and the dried seeds are much more tolerant of mechanical actions than moist seeds. The usual sequence of operations is: (1) removing large materials (scalping), (2) dewinging (not necessary for NRS collections), (3) removing small debris and empty seeds, and (4) conditioning (including sizing) to improve seedlot quality. In some seed plants, sizing is done before final cleaning to facilitate removal of empty seeds. It is important that seedlot identity be maintained and that all equipment be thoroughly cleaned between lots. This last point cannot be emphasized too strongly; as equipment is shut down, many seeds remain inside.

4.4.3.1 Scalping

Scalping primarily removes debris larger than seeds (limbs, pine straw, large cone fragments, etc.), usually with an air-screen cleaner with two or three screens and one air system [116]. NRS collections often yield lots with dewinged seeds and considerable pine straw. Scalping in these lots can also be done with an inclined draper; with this device, seeds roll or slide down an inclined moving belt and leave pine straw behind [19, 100].

4.4.3.2 Dewinging

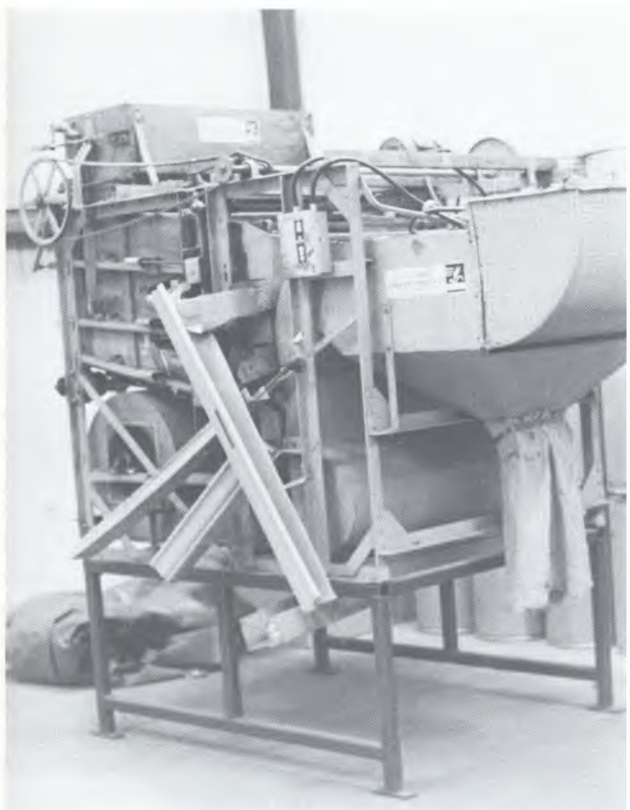
Dewinging can be done mechanically either dry or wet. At one time, all southern pines were dewinged dry with a machine built to polish popcorn. However, improper operation of this machine caused considerable damage to seeds, and it is now used only rarely. Dry dewingers designed for tree seeds are available commercially, and the risk of damage is minimal because the cylinders are lined with soft rubber to reduce the abrasive forces on seeds [85]. Large dry dewingers, built to continuously process up to 90 kg/hour (200 lb/hour) [116], have aspirators to remove dust, wing fragments, and resin particles. One small dry dewinger uses gum rubber flaps on the center shaft as well as rubber cylinder lining to minimize damage [86]. Although designed for western conifer lots of 4.5 kg (10 lb) or less, this machine will dewing loblolly pine and, presumably, other southern pines. The hardest pine to dewing without damage is longleaf; dry dewinging is recommended, but extra care is needed [19].

Wet dewinging is more popular for southern pines (except longleaf) because the risk of seed damage is less. Seeds are moistened with fine water spray or mist as they are slowly turned in a drum or cylinder. The hygroscopic wings absorb moisture quickly and are broken off by rubbing against other seeds; no brushes are necessary. Commercial models include aspiration to remove fine debris and wing fragments. Capacities are the same as those of dry dewingers — up to 90 kg/hour (200 lb/hour) [116]. A small cement mixer can be used to dewing small batches of seeds; water can be sprayed by hand on seeds as the mixer turns and stopped when the first wings come off. Laboratory samples can be safely dewinged in a laboratory blender. The chamber is filled half with winged seeds, half with water; about 10 seconds at the slowest blender speed will dewing the seeds easily without damage.

If wet dewinging is done properly, very little moisture is absorbed by the seeds. However, seed moisture contents should be quickly checked with an electronic meter after wet dewinging (see 4.5.2.1). If moisture content is above 10%, seeds should be redried with a kiln or any system that forces dry air through the seeds; minimal heat is needed in this operation. Commercial models of batch seed dryers are available.

4.4.3.3 Cleaning

The basic cleaning machine for all types of seeds is the air-screen cleaner (Fig. 4.7A), which employs up to seven screens and four air systems to remove debris and empty seeds and size the good seeds. A recent modification of this machine is the flat screen cleaner (Fig. 4.7B). Large air-



(A)

(B)

Figure 4.7. Two types of screen cleaners: (A) traditional air-screen cleaner; (B) flat screen cleaner.

screen cleaners can handle up to 2,700 kg (6,000 lb) of seed/hour [100], but most pine-seed extractories use smaller models with five screens, two air systems, and maximum capacities of no more than 680 kg (1,500 lb) of seeds/hour. A large air-screen machine can scalp, clean, and size good seeds and remove empty seeds in one pass, but results are usually best if these tasks are separated. A typical extractory might use one machine to scalp (two or three screens, one air system) and a second machine to do final cleaning to remove small debris and broken seeds (four or five screens, two air systems) and perhaps sizing. With two air-screen machines, scalping and cleaning can proceed at the same time; with only one machine, screens must frequently be changed. Screen selection depends on the species to be cleaned, type of debris, size of the cleaner, and condition of the lots when they reach the cleaner. Extractory managers should confer with equipment representatives to make these choices.

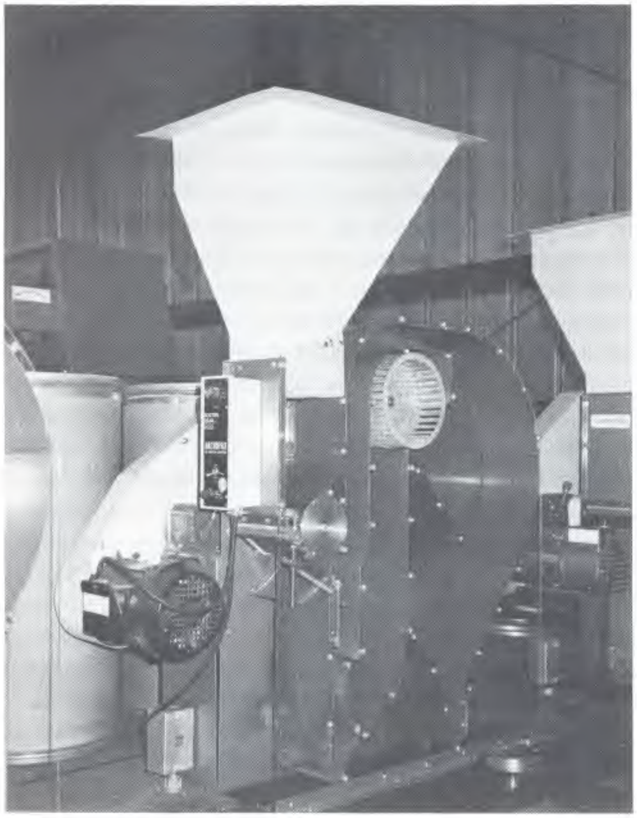
Another cleaning technique available for loblolly seeds is water flotation. Although flotation is primarily used to remove empty seeds (good loblolly seeds sink in water), it can also help clean the lot by removing large trash that floats. Seeds must be redried after flotation. Large commercial aspirators also can remove small debris from pine seeds, but their use in cleaning southern pine seeds is not common.

4.4.3.4 Conditioning

Once all debris has been removed, seedlots can be conditioned to improve their value. Removing empty seeds is a basic step, although many extractories have already done this with cleaning. Empty and partially filled seeds are sometimes removed with a fractionating aspirator (Fig. 4.8A), an efficient device for specific-gravity separations. Empty seeds can also be effectively removed on gravity tables [113]. (Fig. 4.8B).

Seed sizing is also a conditioning operation. Although the relationship of seed size to germination rate and seedling size in southern pines varies by geographic source [37], sizing in nursery operations can be advantageous. Sized seedlots are generally easier to plant than multisized lots and should provide more uniform emergence and spacing in nursery beds. Sized seedlots are desirable when nursery sowing is done with precision seeders. Multiclonal mixtures should always be sized. Seed managers may be tempted to discard the small-seed fraction of their lots and plant only the medium and large fractions; however, such a practice would eliminate certain families and narrow the genetic base of the planting stock [62, 109]. All sizes should be utilized in seedling production. When seeds are kept separate by clones, sizing is optional. Some managers divide clonal lots into as many as three sizes; others do not size clonal lots.

Seeds are sized most efficiently with screens, although gravity tables also can be used. A study with slash pine [21] found that sizing with screens improved uniformity within the seedbed, but sizing on a gravity table did not. Gravity



A

Figure 4.8. Two machines commonly used to condition seeds of southern pine: (A) aspirator; (B) gravity table.

B

tables and fractionating aspirators can upgrade seedlots by separating seeds within size classes into density gradients. This step, which removes immature, partially filled, or insect- and disease-damaged seeds [7o, 113], can greatly increase the value of some seedlots, but not others.

A new, potentially valuable upgrading technique — the IDS (incubation-drying-separation) method — is currently being assessed for southern pine seeds. Developed in Sweden with the small seeds of lodgepole pine *(P. contorta* Dougl. ex Loud.), IDS separates filled, nonviable seeds from filled, viable ones [110]. The seeds are incubated at 15°C to initiate germination, then dried at 25°C to interrupt it. During drying, viable seeds retain more moisture than nonviable seeds, and the weight difference can be utilized to separate the two fractions by flotation or other means. Early results with slash pine have been promising [49], and research trials with slash and loblolly are currently underway [121].

4.5 Seed Testing

Good seed-management decisions cannot be made without a thorough knowledge of the characteristics of the product. This means that test samples must be truly representative of the whole lot, and that proper testing procedures must be carried out by competent analysts. Physical characteristics of the seed should be examined or tested during collection, extraction, and processing. Once seeds are cleaned, germination should be tested by an appropriate method. Stored seeds should be checked every 2 to 3 years. Recentness of germination tests may be prescribed by state seed laws in commercial sales, and all seed buyers should require tests within 6 months of sale.

Seed tests can be obtained in commercial laboratories, the National Tree Seed Laboratory, possibly some state seed-testing laboratories, or in-house facilities established by companies to furnish test data for their own regeneration programs. In seed sales, third-party testing should always be required. Although the National Tree Seed Laboratory has traditionally provided third-party testing because most state laboratories do not want to test tree seeds, several commercial laboratories now can furnish reliable third-party services.

4.5.1 Sampling

A seedlot is defined as a unit of seed of reasonably uniform quality from a particular geographic source or elevation. Past practices with southern pines have specified a 455-kg (1,000-1b) "unofficial" limit on lot size. Any lot larger than this size should be divided into two smaller ones.

Drawing the sample is extremely important: it must be representative of the whole lot to be of value. Pine seeds are free-flowing and can be easily sampled with hollow, slotted brass tubes called triers. For lots held in one to six containers, samples should be drawn from each container, with a total of at least five samples; for more than six containers, five containers plus 10% of the total number should be sampled [2]. For example, if a loblolly pine lot of maximum size were stored in 2-hL (55-gal.) drums (-115-kg/drum capacity), then there would be four containers to sample. If the same lot were stored in the more common 0.9-hL (24-gal.) drums (50-kg/drum capacity), there would be nine containers, which would require a minimum of six drums to be sampled. Each drum should be sampled from the top, middle, and bottom, and all samples should be combined and mixed into a single composite [19]. Stored lots should be sampled in cold storage and samples placed in moisture-proof containers before coming in contact with warm air. Without protection, moisture will condense on cold seeds and alter seed moisture content and weight.

The composite sample should be halved to secure the "submitted sample" (that submitted to the laboratory) [2], which must provide at least 2,500 seeds for purity and germination tests (Table 4.5). If only a germination test is requested, a minimum of 600 seeds is required [2]. Samples should be clearly labeled and shipped in nonbreakable, preferably rigid, containers. If moisture content is to be determined, the container must be moisture-proof.

4.5.2 Physical Characteristics

Physical characteristics are the first parameters measured in laboratory testing. Because moisture content may change during sample handling, it should always be measured first.

4.5.2.1 Moisture content

Seed moisture content, a very important characteristic, is measured not only in the testing laboratory, but also during seed processing. The development of inexpensive, reliable, electric seed-moisture meters has made the quick estimates possible during processing.

Table 4.5. Minimum sample sizes of southern pines submitted for official seed testing by Association of Official Seed Analysts rules [2].

Pine species	Minimum sample, g	Pine species	Minimum sample, g
Eastern white	40	Sand (both races)	15
Loblolly	60	Shortleaf	25
Longleaf	250	Slash	70
Pitch	20	Spruce	25
Pond	20	Virginia	20

Figure 4.9. Two types of electric moisture meters suitable for pine seeds.

Moisture content should be measured as soon as possible after samples are received in the laboratory. Testing rules of the AOSA [2] do not cover moisture testing, but those of the International Seed Testing Association (ISTA) [73] do. ISTA procedures must be used on any seeds involved in international trade, and experience has confirmed their suitability for southern pines. Duplicate samples of 5 g each, drawn from the submitted sample, should be weighed to the nearest milligram, placed in containers of noncorrosive metal or glass, and dried in a mechanical convection oven at 103 ± 2°C for 17 ± 1 hours. Samples should be transferred from the oven to a desiccator for 30 to 45 minutes of cooling, then reweighed. Moisture contents are expressed as a percentage of sample wet weight:

$$\text{Moisture content} = \frac{\text{wet weight} - \text{dry weight}}{\text{wet weight}} \times 100.$$

If the difference between the duplicate samples exceeds 0.3%, ISTA rules [73] require that the procedure be repeated. Detailed guidelines for measuring moisture in tree seeds are available [27].

Electric moisture meters that work on the principle of electrical resistance or capacitance provide rapid non-destructive testing (Fig. 4.9). Most are accurate to within 1% or less of values determined by oven drying [27]. Required sample sizes range from 85 to 200 g, depending on species or type of meter, and this requirement should be followed precisely. Some meters indicate total moisture in the measurement chamber; therefore, meter readings must be converted to moisture percentage with calibration charts (Table 4.6), which demands that a constant sample weight be used each time. Additional information on electric moisture meters is available [25, 27].

Table 4.6. Moisture contents of southern pine seeds for corresponding values on the 'A' scale of a Burrows, Dole or Radson meter. [1]

Pine species	Sample size, g	Moisture content, %												
		6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.00	10.5	11.0	11.5	12.0
Eastern White	142	78	80	83	86	90	94	98	104	108	114	119	124	129
Loblolly	142	78	81	84	87	90	93	95	98	101	103	106	109	111
Longleaf (dewinged)	85	45	46	48	50	52	53	55	57	58	60	62	64	66
Longleaf (winged)	85	41	43	45	47	49	50	52	54	56	58	60	62	63
Pond	142	76	78	80	81	84	86	89	92	96	100	105	110	114
Shortleaf	142	76	80	82	85	88	92	95	99	103	107	112	116	120
Slash	142	70	74	77	81	84	87	91	94	97	100	101	105	108
Virginia	142	74	77	79	82	86	88	92	96	100	105	110	114	119

[1] Data supplied by U.S.D.A Forest Service, National Tree Seed Laboratory, Macon, Georgia, in cooperation with Eaton Corporation.

Ovens or electric meters are fine for rapid estimates and official tests, but research studies may demand greater accuracy. Several laboratory techniques meet this requirement [25].

4.5.2.2 Purity

Purity tests determine what proportion of the sample by weight is pure seed of the designated species and what proportion is other material. If the submitted sample is of minimum size (Table 4.5), all of it is used for the purity test; if larger than the minimum, the sample should be reduced by halving to obtain a working sample equal to the weights in Table 4.5.

The working sample is divided into four components:
(1) Pure seed of the test species.
(2) Seed of other tree species.
(3) Weed seed (very important for NRS collections).
(4) Inert material (leaves, cone scales, rocks, etc.).

Under AOSA rules [2], the pure seed component includes immature or undersized seeds, cracked or otherwise damaged seeds, pieces of seeds larger than one-half of original size, insect-damaged seeds, and germinating seeds. Inert material includes seeds without seed coats, broken seeds less than one-half of original size, unattached wings, attached wings except for the part that encloses the seed and which may not be removed in seed conditioning, and seedlike structures (wings with thick bases that obviously are not seeds).

Each component is weighed and its weight expressed as a percentage of the total weight of the working sample. Good seed processing should always yield purities of 95% or more for southern pines. NRS collections are challenging plant managers because of the amounts of weed seeds and inert material in the lots; nevertheless, good cleaning operations should obtain 95% for these lots also.

4.5.2.3 Weight

Seed weight, essential for sales and for calculating sowing rates, is determined from the pure seed fraction of the purity test and includes empty seeds if present in the sample. Five replicates of 100 seeds each should be randomly drawn and weighed to three significant digits. If the difference between any two replicates exceeds 10% of the mean weight, additional replicates should be drawn. This discrepancy is highly unlikely in clonal collections, but may occur frequently in mixed-orchard or wild-stand collections. Multiply the mean weight (in grams) by 10 to convert to "weight of 1,000 seeds," a term commonly used to express seed weight. To convert the resulting value to number of seeds per unit weight, calculate as follows:

Seeds/kilogram = 1,000,000/weight of 1,000 seeds,

or

Seeds/pound = 453,600/weight of 1,000 seeds.

Note that

Seeds/kilogram = seeds/pound x 2.2
Seeds/pound = seeds/kilogram x 0.454.

4.5.3 Germination

No test is more important than the germination test: it tells the seed manager the full potential of the seedlot.

Table 4.7. Germination test conditions recommended for southern pines by the Association of Official Seed Analysts [2].

Pine species	Prechill, days	Temperature, °C	Duration, days
Eastern white	28–42	20–3-; 22[1]	28
Loblolly	28[2]	20–30; 22	28
Longleaf	0	20	21
Pitch	0	20–30	14
Pond	0	22	21
Sand (both races)	0	22	21
Shortleaf	0[2]	20–30; 22	28
Slash	0[2]	20–30; 22	28
Spruce	21	20–30	16
Virginia	0	20–30; 22	21

For some species, two different conditions are approved, alternating 20 and 30°C and a constant 22°C. Light must be supplied for 8 hours each day in conjunction with the 30°C period in the alternating regime.

[2] Species that exhibit variable dormancy. Paired tests (4 replicates with prechill, 4 without) are desirable.

Although this potential may not be reached because of bad weather, poor soil, human error, or other factors, the guiding philosophy of seed testing is to use controlled, optimum conditions for germination to determine full potential. In this way, meaningful comparisons are possible among seedlots and testing laboratories. Nursery managers or other seed users must learn to relate laboratory test results to seedlot performance under their own local conditions.

The most reliable test is to germinate a representative sample of the lot. Four replicates of 100 seeds each are randomly drawn from the pure seed fraction (see 4.5.2.2). Standard test conditions (Table 4.7) can be maintained in walk-in germination rooms or laboratory germinators. If walk-in rooms are used, the samples must be placed on a moist medium in closed, transparent boxes to maintain high seed-moisture content. Most laboratory germinators are designed to maintain high humidity, so seeds can be placed on open trays of moist substrate. Some tests for southern pines now use paper substrates such as paper blotters, paper toweling, filter paper, or creped cellulose wadding. However, all substrates must (1) be nontoxic to seedlings, (2) be relatively free of microorganisms and their spores, and (3) provide adequate aeration and moisture for germinating seeds [74]. Maintaining an even moisture supply in the substrate is critical for good testing. Excessive moisture can restrict aeration and favor damping-off fungi (see chapter 20, this volume). Paper substrates should not be so wet that a film of water forms around the seeds, or that, by pressing, a film of water forms on the finger. Several good commercial brands of paper substrates are made solely for seed germination.

Light promotes rapid germination of southern pine seeds, though it is not an absolute requirement. Dormant seeds, in particular, benefit from some light during germination tests. AOSA rules [2] prescribe 54 $1m/m^2$ (50 ft-c) as a minimum for tree seeds, with 81 to 108 lm/m^2 (75 to 100 ft-c) preferred. There is good evidence for phytochrome-mediated response to light in longleaf [99] as well as loblolly and eastern white [115] pine seeds.

Research data support both alternating [51, 70] and constant temperatures [20] as optimum for germination tests of southern pines. With nondormant or properly prechilled (stratified) lots, either temperature regime (alternating 20 to 30°C or constant 22°C) will give complete germination in the prescribed time period. Tests with dormant loblolly on a 2-way thermogradient plate, however, showed that alternating temperatures increased germination rates over those obtained at constant temperatures [28]. Seeds under constant temperatures from 15 to 34°C benefited more from prechill than did seeds under most alternating temperatures. In actual practice, managers can use either regime with confidence.

Species that commonly exhibit dormancy — eastern white, loblolly, and spruce — should be prechilled before germination testing (Table 4.7). Some lots of slash and particularly shortleaf exhibit dormancy and will need prechill for complete germination within the 28-day test period. On the other hand, some loblolly lots are practically nondormant. Because of this variation, paired tests (4 replicates with prechill, 4 without) are recommended for loblolly, shortleaf, and slash. Nursery managers or other seed users can make much better seed-treatment and sowing decisions with results from paired tests.

Germination is counted every seventh day of a test in most laboratories. If all seeds are not germinated at the end of the test period, the test should be extended for another 7 days. All ungerminated seeds should then be cut open and their condition scored as empty, nonviable, or viable but ungerminated (dormant). If many dormant seeds are found, the test should probably be repeated with an increased length of prechill.

Total percent germination by itself does not always provide enough information on the value of a seedlot. Although the total germination of two lots may be equal, their vigor[2] may be quite different. Small differences in vigor in the laboratory usually predict much larger differences in the nursery or field, where germination environments are more stressful.

Many types of vigor tests other than the germination test have been evaluated for southern pines — biochemical tests, seedling growth tests, and mathematical modeling of germination behavior [14, 31, 36] — but the most consistent indicators of seed performance of loblolly, slash, shortleaf, longleaf, Virginia, and eastern white pines have been total percent germination, germination rate, and, in some cases, leachate conductivity [14, 31, 35]. Total percent germination is a good indicator with nondormant seeds, but as dormancy increases, germination rate is better. Good expressions of rate are peak value and germination value [47]. Peak value is the largest quotient obtained when cumulative percent germination on each test day is divided by the number of days since the test began. Germination value, designed to reflect both speed and completeness of germination, is the product obtained when mean daily germination percent is multiplied by peak value. A complete germination test is required to obtain these values. Leachate conductivity, which relates electrical conductivity to seed quality, can be determined in 24 hours (see 4.5.4). Readers are referred to AOSA [2] and ISTA [73] rules and other summary publications [19, 25, 114] for the many other aspects of pine seed testing that cannot be covered here.

4.5.4 Indirect Estimates of Quality

A laboratory germination test often is not possible because of time constraints. When this situation occurs, managers may use one of several rapid, indirect estimates of seed quality: cutting tests, X-ray, tetrazolium staining, or leachate conductivity.

[2] AOSA has defined seed vigor as follows [3]: "Seed vigor comprises those properties which determine the potential for rapid, uniform emergence and development of normal seedlings under a wide range of field conditions."

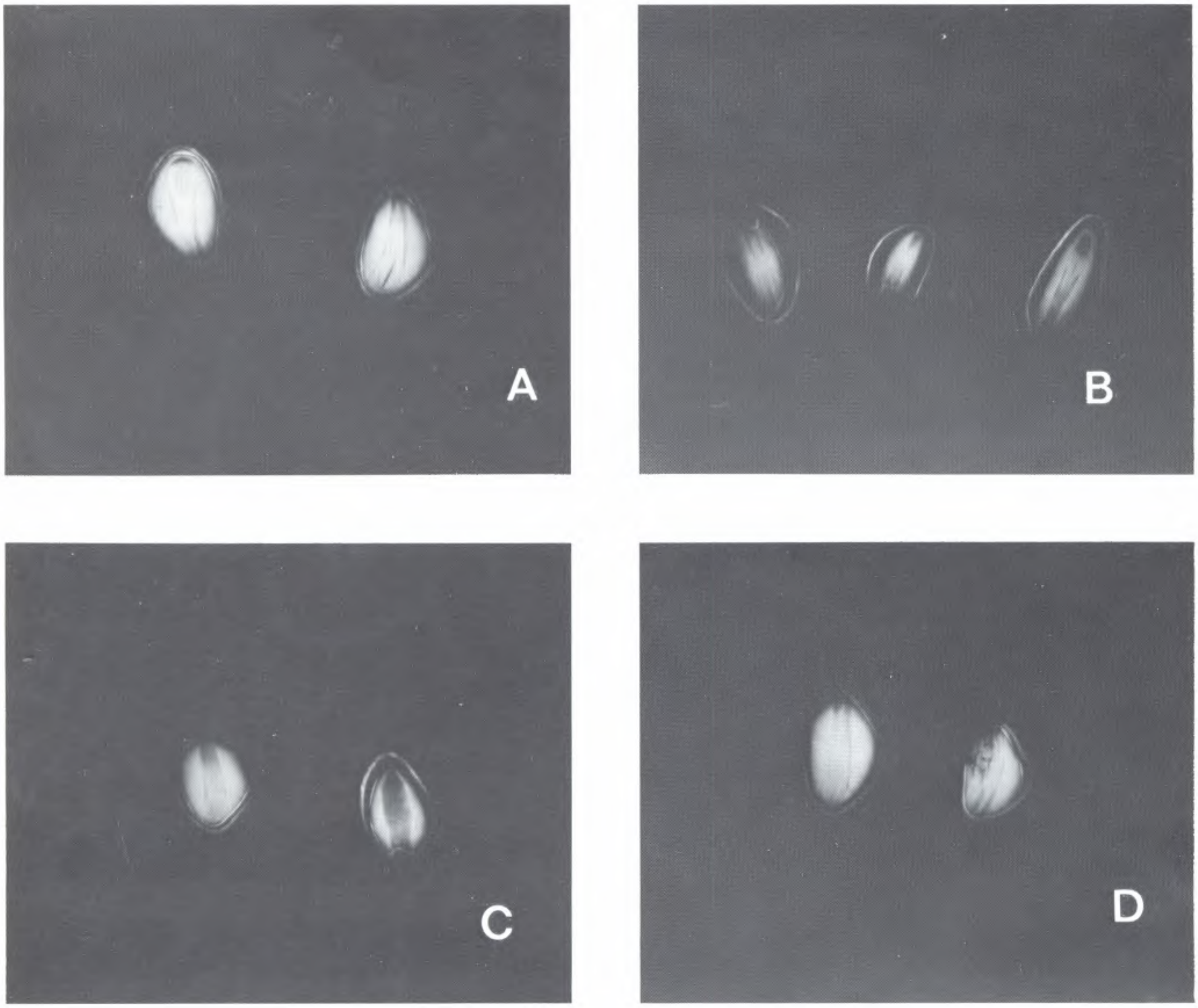


Figure 4.10. Radiographic images of slash pine seeds: (A) filled (potentially sound); (B) incomplete gametophyte tissue; (C) distorted embryo (left), missing embryo (right); (D) mechanically damaged seeds (adapted from [44]).

Cutting tests, the simplest and oldest of all seed tests, are surprisingly reliable for fresh seeds but should not be used on stored seeds, because loss of seed quality in storage may not produce immediate visible changes. Pine seeds should be cut in half along the length of the embryonic cavity. Good seeds are typically those that have fully grown, firm, undamaged tissue with a creamy white color. Longleaf seeds may exhibit a greenish tint from chlorophyll development, but this does not always imply deterioration.

X-ray, pioneered in the South at the National Tree Seed Laboratory and widely used on southern pine seeds, can indicate empty seeds, insect damage, some advanced disease damage, incompletely developed or abnormal embryos, and some mechanical damage (Fig. 4.10). If the seeds are treated with contrast agents, hard-to-detect damage such as bruised tissue and cracks in the seed coats may become evident [17]. The X-ray test is rapid (24 hours or less) and nondestructive, leaving a permanent record for later study, but equipment is expensive and radiographs are difficult to interpret. A recent AOSA handbook offers help for evaluating seed condition from radiographs [23]. Film type also is important. Polaroid® film or radiographic paper can be developed quickly, but neither captures the same detail as conventional radiographic film.

Tetrazolium (TZ) staining is a biochemical test that indicates the presence of live tissue. A 1% solution of a tetrazolium salt (usually 2, 3, 5-triphenyltetrazolium chloride) is applied to fully imbibed seeds cut lengthwise (without damaging the embryo) to facilitate entry of the solution. Test seeds are incubated in the solution for 18 to 24 hours in the dark at 30°C [73]. Active dehydrogenase enzymes reduce the TZ to a stable, red triphenyl-formazan that is insoluble in water. Dead tissue does not stain, but live tissue stains pink to red. Localization and proportion of necrotic tissue, not just color intensity, are the keys to classifying seeds as viable or nonviable. The subjective nature of classification is a major drawback to TZ staining, and the test is also labor-intensive. But the test period is short and the equipment inexpensive. In fact, the short test period led to adoption of TZ staining as an official test procedure for many deeply dormant species [2, 73], a condition not really relevant to southern pines. Although TZ staining has been used on southern pines for rapid testing [65], X-ray has been much more common for this purpose in the last 20 years. Adequate guidelines on the use of TZ on pine and other conifer seeds are available [73, 83].

Leachate conductivity is a new, rapid, nondestructive technique. Seeds are leached for 24 hours in deionized water, and electrical conductivity of the leachate is then measured and related to seed quality. As seeds deteriorate or are damaged, their membranes begin to "leak" cellular substances, some of which are electrolytes. Increased leaching leads to increased electrical conductivity, which is related to decreasing seed quality. Preliminary tests have predicted laboratory germination of loblolly to within 6.5% of actual, and of slash to within 7.2% [123]. Results for longleaf, shortleaf, Virginia, and eastern white pines [40] also have been promising. This method is easy, speedy (24 hours), and objective; but equipment is costly, and unknown factors can affect measurements. Current research efforts should identify and eventually eliminate the latter.

4.5.5 Labeling and Certification

Good recordkeeping practices demand that all samples be labeled properly during all testing procedures. Loss of seedlot identity is one of the worst things that can happen to a seed manager. If seeds are to be sold or certified, certain labeling practices may be required by law. The following southern states specifically include tree seeds under their labeling laws: Maryland, Mississippi, Virginia, and West Virginia [1]. Tree seeds sold in these states, even without certification, must be labeled as to species, percent germination, and other items, depending on the state.

If certification of a seedlot is obtained from one of the state seed-certifying agencies (see 4.2.6), then the appropriate label, or certificate, must be attached to lot containers. The information required on labels for certified lots varies among states, but in all cases exceeds the information required on ordinary sale labels in the four states that require them.

4.6 Seed Storage

The uncertainty of cone production requires seed managers to store seeds to offset years of low production. And while good seed-orchard management has reduced the fluctuation in southern pine cone crops, no manager can afford not to have back-up seed supplies in storage. Fortunately, seeds of southern pines are relatively easy to store for long periods.

Seeds may be stored to meet one of several objectives whose storage requirements differ. For example, seeds collected and cleaned in November and scheduled for planting the following spring require only minor refrigeration if moisture contents are at proper levels. Seeds to be used within 3 to 5 years, a common inventory supply period in the South, need lower storage temperatures. Long-term storage[3] for germplasm conservation or other reasons requires the best storage environment possible; however, facilities are expensive to build and maintain. Seed managers should consider what amount of seeds they will need to store to satisfy each objective.

4.6.1 Environmental Conditions

Pines are among the species commonly described as "orthodox" in their storage behavior [105]. This means that viability can be maintained for many years when seeds are stored at low moisture contents and temperatures. Other considerations such as type of container or refrigeration also come into play, but seed moisture and temperature are primary.

4.6.1.1 Moisture content

Seed moisture content is *the* most important factor in seed storage. Southern pine seeds should be dried to < 10% moisture for storage [13]. For short-term storage (3 years or less), higher moisture levels may be acceptable under certain conditions [13, 36], but these conditions are not well defined. Moisture content of 5 to 10% is the current recommendation for successful storage.

The apparent relationship of seed moisture content during storage to degree of dormancy in loblolly pine may be significant. Studies by McLemore and Barnett [97] indicated that moisture contents of 10 to 18% during storage for 1 year increased the degree of dormancy compared to that < 10 and > 18%. Barnett [6] also demonstrated that redrying stratified loblolly seeds to 10% moisture induced a secondary dormancy. A recent study with loblolly confirmed this latter result, but found that the degree of secondary dormancy was inversely proportional to seed moisture content after 6 months of storage [24]. The phenomenon of secondary dormancy is important, in light of the expanding interest in modifying standard prechill to a prechill/drying/storing sequence for western conifers [54]. Some research of this nature has been done with southern pines [18], but more is needed (see 4.7.1.3).

Seed managers must also be aware of the moisture-equilibration properties of their seeds. Seeds exposed to the ambient atmosphere will lose or gain moisture from it depending on seed moisture content, seed chemical content, and ambient humidity; eventually, seed moisture will attain equilibrium with the storage environment. The equilibrium

[3] A period of time longer than one rotation [57].

moisture contents are similar for pines and other orthodox tree seeds: about 10% at 40 to 55% RH, and 17 to 20% at 95% RH, at 4 to 5°C [27]. Most refrigeration systems used for pine-seed storage in the South do not have humidity controls, so RH is always above 90%. To avoid moisture uptake and equilibration at 17 to 20%, seeds must be stored in moisture-proof containers. Humidity control is possible, but expensive. In such coolers, where RH would be 50 to 60%, pine and other orthodox seeds could be stored in burlap bags or any unsealed containers.

4.6.1.2 Temperature

The standard storage recommendations for all orthodox species apply to seeds of southern pines. For short-term storage (2 to 3 years), 2°C is sufficient; for longer periods, —18°C is best [13]. These recommendations also assume seed moisture contents of 10% or less. However, some evidence suggests that higher temperatures might be permissible if moisture contents are 6 to 8% [13, 36]. Until more research results are available, seed managers would be well advised to follow the standard recommendations for temperature.

4.6.1.3 Containers

Any moisture-proof container can be used to store pine seeds. Glass containers are discouraged because of possible breakage. Plastics thinner than 0.1 mm (0.004 in.) are not effective moisture barriers and are easily torn. For large lots, metal or fiberboard drums with plastic liners are excellent; fiberboard drums are probably more popular in the South because they are lighter and easier to handle [19]. For small lots, rigid plastic bottles with good screw-top lids are satisfactory.

4.6.2 Treated Seeds

Occasionally, seeds that have been treated with chemicals are not planted, but are dried and returned to storage until the following year. Barnett and McLemore [13, 96] recommend the following:

(1) Repellent-coated, prechilled loblolly and shortleaf seeds should be stored at —4°C (25°F) without redrying. Additional prechilling is unnecessary.
(2) Repellent-coated, prechilled slash seeds should be dried to 10% moisture and stored at —4°C. Additional prechilling is unnecessary.
(3) Repellent-coated, non-prechilled slash and longleaf seeds should be dried to 10% moisture and stored at —4°C. Because moisture is absorbed during treatment, some drying is necessary.

Some authorities recommend drying all prechilled and treated seeds to 8% moisture before storage [89], but this could be risky for loblolly and shortleaf, which require additional prechill. When moisture is added for prechilling treated seeds, it must be done gradually; immersing treated seeds in water can cause chemical damage [16].

4.6.3 Longevity

Longevity of stored seeds should not be a factor in southern pine regeneration programs. Even longleaf pine, the most difficult of the southern pines to store, can be kept at least 10 years with no significant loss of viability [13]. Viability of slash and shortleaf seeds stored 50 years was 66 and 25%, respectively [15]; vigor declined as expected, but no serious chromosomal damage was found (shortleaf only).

The potential storage life of southern pine seeds under optimum moisture and temperature conditions is actually unknown, but could approach 100 years [32]. Moreover, cryogenic storage in liquid nitrogen might extend storage life, which is important for germplasm conservation. Engstrom [56] stored shortleaf seeds in liquid nitrogen for 112 days without damage, and other conifer seeds have been successfully stored for 6 months in a similar fashion [111].

4.7 Seed Treatments

Germination and seedling growth often may be enhanced by seed treatment before sowing, either to overcome dormancy (delayed germination) or to protect seeds and young seedlings from diseases or animal predators.

4.7.1 Prechill (Stratification)

Seeds that exhibit dormancy germinate slowly, even in favorable environments. Loblolly and eastern white pines have the deepest dormancy of the southern pines. Others, primarily Virginia, shortleaf, sand, and spruce pines, have less dormancy and require less treatment to germinate rapidly. The least dormant species, slash, pitch, pond, and longleaf, usually require no treatment for fresh seeds, but may require some for seeds [79] that developed a slight dormancy during storage.

The traditional treatment to overcome dormancy in pine seeds is a cold, moist storage period called prechill, or stratification. The term stratification, primarily used for tree seeds, originated from the early practice of storing seeds in alternating layers (strata) with a moist substratum in outdoor pits to simulate natural conditions over winter. Modern application employs refrigeration instead of the outdoors, and fully imbibed seeds are kept in plastic bags. Moisture-holding media may be placed in bags with the seeds but usually are not. Because the term prechilling more accurately describes the current procedure, it is preferred over stratification. An alternative treatment for southern pines uses aerated water soaks at 5°C [5]. Though successful in overcoming dormancy, this approach demonstrates no advantage over standard prechill.

Prechill meets several objectives:

(1) Any physiological afterripening requirements are satisfied. Growth-regulator levels are known to change during prechill of loblolly, but no strong

evidence indicates that the changes control dormancy [4, 8, 103]. Seedcoat constraints are apparently much more important [8], and these presumably decrease as a result of afterripening.

(2) Seeds achieve full hydration before sowing. This often-overlooked benefit of prechill means that enzyme systems are active and stored food reserves readily available. Otherwise, full hydration would have to develop after sowing and uptake of soil moisture, significantly delaying germination.

(3) Seeds on the verge of germination are delayed by the low temperatures. This causes a rapid flush of uniform germination after sowing, a condition that enhances production of plantable seedlings [42, 125].

4.7.1.1 Conditions

Successful prechill has three major requirements [38]: (1) source of moisture, (2) low temperatures, and (3) adequate aeration. Moisture should be supplied by soaking seeds in water for 17 to 24 hours at room temperature. Longer soaks may damage seeds. The seeds should then be drained and put in polyethylene bags with a wall thickness of no more than 0.1 mm (0.004 in.). No more than 11 kg (25 lb) of fully imbibed seeds should be placed in each bag [38].

The bags should be refrigerated at 1 to 3°C (34 to 38°F). Both higher [38+°F] and lower (below freezing) temperatures can cause damage. For proper aeration, the bags should not be completely filled. They should be turned weekly, and some should be opened and checked for an alcohol odor, which indicates anaerobic respiration as a result of poor aeration. Aeration can be improved by poking holes in the bottom of the bags. Additional information on prechill for tree seeds is available [19, 38, 54, 114].

Table 4.8. Recommended prechill periods for nursery sowing of southern pines. (adapted from [19, 79, 120]; and unpubl. data, Southern Forest Experiment Station, Starkville, Mississippi.

Pine species	Normal sowing period: Fresh seed	Normal sowing period: Stored seed	Early sowing[1]	Seed lots with: Extreme dormancy[2]	Seed lots with: Low vigor
		days			
Eastern white	30–60	60	60–90	60–90	30
Loblolly	30–60	30–60	60	60–90	20–30
Longleaf	0	0	–	0–15	0
Pitch	0	0–30	–	–	–
Pond	0	0–30	–	–	–
Sand					
Choctawhatchee	0–15	0–21	–	–	–
Ocala	0	0	–	–	–
Shortleaf	0–15	0–30	15–30	30–60	0
Slash					
var. *elliottii*	0	0–30	–	15–30	0
var. *densa*	30	0–30	–	–	–
Spruce	30	30	–	–	–
Virginia	0–30	30	30	–	–

[1] Spring sowing when mean minimum soil temperature at seed depth < 10°C.
[2] Dormancy demonstrated by paired tests or past performance of the lot.

4.7.1.2 Length of prechill

Length of the prechill treatment may vary according to its purpose. For laboratory testing, recommended prechill periods appear in Table 4.7; for nursery sowing, where germination conditions are sure to be less favorable, longer periods may be necessary (Table 4.8).

Several studies have demonstrated improved rate and uniformity of germination with prechills longer than 30 days [11, 43], and some southern nurseries use periods as long as 90 days for loblolly. Excessive prechill can be harmful, however, to damaged lots or to lots with little or no dormancy [14, 43]. Damage to seed quality in the latter situation can result from germination during prechill, especially if temperature control is not precise [11]. Long prechill periods should be used only for lots with demonstrated dormancy or when low soil temperatures are expected at planting. In cold seedbeds, short periods of prechill can be helpful for species that are usually sown without it. In fact, just the 24- to 48-hour imbibition period can aid germination [19].

Stored seeds often require longer prechill than fresh seeds, apparently because dormancy has been increased by the drying treatment to reduce moisture content for storage. On the other hand, prechill periods should be shortened for fresh or stored lots known to be of low vigor; normal prechill of such lots usually decreases their germination [114]. Prechill periods recommended for nursery sowing of southern pines (Table 4.8) are often longer than those recommended for laboratory tests (Table 4.7). If at all possible, choice of prechill period should be based on results of paired germination tests (see 4.5.3). Previous performance of the same lot, family, or geographic source should also be reviewed.

4.7.1.3 Prechill priming and double prechill

Two new techniques — prechill priming and double prechill — have recently been introduced in the South. In prechill priming, a prechill/drying/storage sequence developed with western conifers [54], seeds are prechilled to bring them to the brink of germination, then redried to an intermediate moisture content (usually about 25%; below full moisture but above storage levels) that prevents germination. Seeds are stored for up to 12 months at this intermediate moisture content. The prechill stimulus does not diminish, and germination response frequently improves [54]. Preliminary tests with southern pines, however, have so far shown little improvement with this method compared to standard prechill [11].

In double prechill, a modification of prechill priming, prechilled seeds are redried to below 10% moisture, stored as before, then prechilled again before use. This double treatment, reported to have an additive effect over that of the first prechill in loblolly [43], has often been applied when prechilled seeds could not be used as planned and were dried and returned to storage. However, double prechill has rarely been compared with single prechill. More research is needed to demonstrate the value of prechill priming or double prechill for improving the performance of southern pine seeds.

4.7.2 Protective Treatments

Southern nursery personnel have long treated seeds with thiram or anthraquinone to repel birds. These treatments, developed primarily for direct seeding [48], can be effective if done properly but can retard germination if excessive. Procedures outlined by May [89] should be consulted. Thiram also effectively controls damping-off fungi without damaging germination [104]. Seed soaks or dressings of the systemic fungicide Bayleton® have been successfully tested for early control of fusiform rust in nursery beds without damaging germination [67, 78]. Seeds treated with Bayleton can also be treated with thiram without negatively affecting the Bayleton treatment [78]. Once treated seeds have been surface-dried, some nursery workers dust them with aluminum powder to enhance their flow through seeders.

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