

*6

Techniques of Seed Production and Handling

learning objectives

- Determine different sources for seeds.
- Describe harvesting and processing of different seeds.
- Explain seed tests and their uses.
- Characterize different seed treatments to improve germination.
- Describe principles and procedures for seed storage.

INTRODUCTION

More plants are propagated for food, fiber, and ornamentals from seeds than any other method of propagation. Seed propagation is the cornerstone for producing agronomic, vegetable, forestry, and many ornamental plants. The production of high-quality seeds is of prime importance to propagators. In the production of any crop, the cost of the seed is usually minor compared with other production costs, yet, no single factor is as important in determining the success of the operation. Most crop plant seeds are produced by companies that specialize in both plant breeding and seed production. Growers expect these companies to introduce improved cultivars, as well as to produce high-quality seeds that have good germination characteristics and are true-to-type. To produce high-quality seeds, companies must not only pay close attention to the environment where seeds are produced, but must also have the means to test the quality of those seeds. This chapter discusses various aspects of seed production, testing, and storage. The steps taken to produce, clean, and store seeds for commercial crop production are summarized for a variety of crops in Table 6–1.

SOURCES FOR SEEDS

Commercial Seed Production

Commercial seed production is a specialized intensive industry with its own technology geared to the requirements of individual species (Fig. 6–1, page 164). This section on sources for seeds will be separated into herbaceous and woody plant seeds.

Agricultural, Vegetable, and Flower Seed (35, 50, 98) Historically, seeds for next season's crop were collected as a by-product of production. Although some seeds may still be produced in this manner (e.g., some Third World production), modern seed production has become a very specialized industry (32, 134). A scheme for producing quality seed is included in Figure 6–2 (page 165).

Some agricultural seeds—such as corn, wheat, small grains, and grasses—are produced in the area where the crops are grown. The advantages for producing seeds in their production area include reduced transportation and handling costs as well as reduced potential for genetic shift (see Chapter 5). These are important considerations for agronomic crops where large amounts of seeds are required to produce a crop. However, crop production

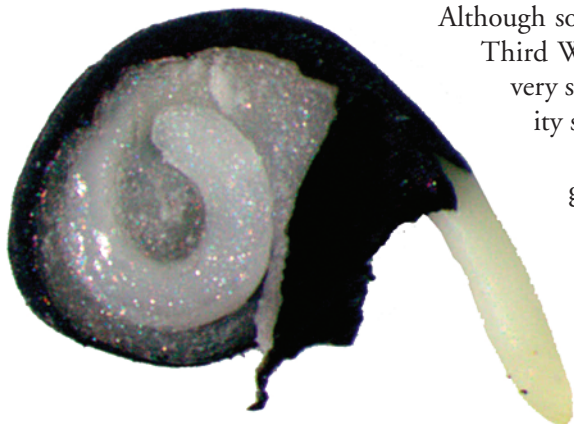




Table 6-1
STEPS FOR PRODUCING, CLEANING, AND STORAGE OF SEEDS FOR COMMERCIAL CROP PRODUCTION

Crop	Production practices	Seed conditioning	Seed storage	Seed treatments
Sweet corn	Hybrid seed production from two inbred parents by wind pollination. Female parent requires detasseling before pollen is shed and is interplanted with rows of the male pollen parent.	Corn cobs are harvested when the seeds are between 35 and 45% moisture to avoid mechanical injury during harvest. Cobs are force-air-dried to about 12 to 13% moisture where the seeds are mechanically removed from the cob. Final moisture is removed in a drying oven (35 to 40°C).	Stored at 10% moisture at 10°C.	Usually treated with fungicide and/or insecticide. Often applied in a polymer film coating.
Tomato	Hybrid seed from inbred parents by hand pollination. Seed parent may be male-sterile, or hand emasculation of anthers is required.	Fruit pulp is separated from the seeds by juice extracting equipment. Extracts can be fermented for 2 to 3 days until the seeds separate from fruit gel and sink. Treatment with HCl acid (5%) is also used to extract seeds after several hours. Excessive fermentation or chemical treatment reduces seed quality. Seed drying should not exceed 43°C.	Stored at 6% moisture at 5 to 10°C.	Can be treated with a fungicide or, in some cases, primed.
Onion	Hybrid onion seed is produced by insect pollination between inbred parents. The female seed parent is male-sterile. Plants flower (bolt) after the second season. It is common to plant seed at close spacing the first year to produce small bulbs that are replanted at the appropriate spacing for seed production the second spring.	Seed maturity can vary because flowering umbels are not all initiated at the same time on the plant. Harvest the entire umbel when the first individual fruits begin to crack and show black seeds. Umbels are naturally air-dried for 2 to 3 weeks on open benches. These are threshed and seeds are separated by screens, air, and gravity separation.	Seeds of onion are short-lived in storage. Stored at 6% moisture at 5°C.	No special seed treatments.
Impatiens	Hybrid seeds are produced in the greenhouse by hand pollination between inbred parents. Seed parent is pollinated as soon as the stigma is receptive to prevent self-pollination.	Fruit of impatiens explodes when ripe, expelling seeds. Therefore, fruits are harvested prior to expulsion and placed on frames for several days until seeds are shed. Seeds are then air-dried or dried under gentle heat.	Stored between 3 and 5% moisture at 5°C.	Impatiens are a high-value seed crop. Seeds may be primed, pelleted, or pregerminated.
Pawpaw (Asimina)	Pawpaw understocks are produced from seeds. Hand pollination between trees with different genetic backgrounds will increase fruit and seed set.	In most cases, seeds are a by-product of fruit processing. Pulp can be removed by fermentation and washing.	Pawpaw seeds are recalcitrant and cannot withstand seed moisture below 35%. Seeds can be stored moist at 5°C for 2 years.	Stratification (moist, cold storage) for 8 to 10 weeks to relieve dormancy.

(Continued)



Table 6-1 Continued

Crop	Production practices	Seed conditioning	Seed storage	Seed treatments
Pine	Seed orchards are established with elite trees with superior growth characteristics. Seed production takes 18 months and trees take between 2 and 10 years to bear a crop.	For some species, seed is collected on nets under trees after the cones naturally shed seeds. For most, cones are harvested and placed on wire benches where the cones air dry and shed seeds in 2 to 8 weeks. Some cones require oven drying at about 50°C to open cones. Seeds are collected and mechanically dewinged, followed by flotation or gravity separation to get viable seeds.	Stored at 6% moisture and 0 to 5°C.	Stratification (moist, cold storage) for 2 to 12 weeks to relieve dormancy.

Source: Adapted from Desai et al., 1997; McDonald and Copeland, 1997.

areas may not provide the best conditions for producing high-quality, disease-free seeds. Therefore, large amounts of high-value seeds such as forage, vegetable, and flowers are produced in specialized growing areas.

The major considerations for selecting areas to produce seeds are environmental conditions and cost of production (34, 94, 143). Large quantities of grass, vegetable, and flower seeds are produced in areas characterized by low summer rainfall, low humidity, and limited rainfall during the seed harvest season (11, 144). These conditions provide good seed yields and reduce disease problems, especially during harvest when seeds must dry before being handled. There are also crops that require special environmental conditions to flower and set seeds. These include the biennial

vegetable and flower crops that require **vernalization** (a period of cold temperature) to flower (143). Examples are onion and carrot seed production. One-year-old biennial plants used for seed production have been called **stecklings** (65). Plants may be chilled by overwintering in the field, or in some cases, stecklings are brought into a cooler (5°C, 40°F) to satisfy vernalization requirements and shorten the seed-production cycle.

vernalization A period of cold temperature required by plants to induce flowering. In natural systems, these crops grow in late summer, are chilled over winter, and then flower in early spring.

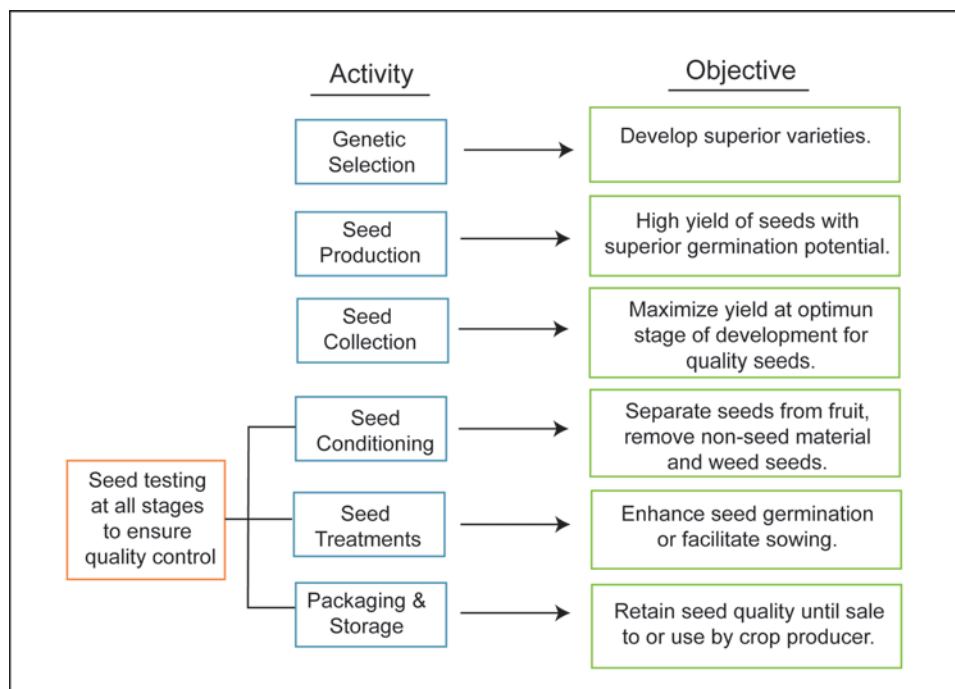
Major production areas for high-value seed production in the United States that meet these important environmental conditions include grass and forage seed production in the Pacific Northwest and vegetable and flower seed production in the Pacific Northwest down to the central, coastal valleys of California (Fig. 6-3). Increasingly, seed production has become an international industry. For example, the United States, Netherlands, and Japan provide over half of the world's flower seeds (61). Hybrid seed production that requires hand pollination has moved to areas of the world with reduced labor costs. These include Central and South America, Southeast Asia, India, and Africa. The advantages to producing seeds in the Southern Hemisphere include a reduced cost of production, and seed production in the season prior to planting in northern crop production areas, which reduces storage time and cost.

Regardless of the country where seeds are produced, there are several important considerations that



Figure 6-1

A majority of important agronomic, horticultural, and forestry crops are propagated by seeds that come in a large diversity of seed size and shape, resulting in diverse requirements for seed production, extraction, and conditioning.

**Figure 6-2**

Procedures for producing and handling a commercial seed lot.



(a)



(b)



(c)



(d)

Figure 6-3

Seed production fields (a) Mallow produced as wildflower seed in Oregon. (b) Wildflowers (coneflower in forefront and grasses behind) production in Wisconsin. California production of (c) cucumber and (d) sunflower with bee hives for pollination.



must be satisfied when selecting specific sites for **seed production** (143, 144):

1. Appropriate **soil type** and **fertility** for good seed yields.
2. A detailed **cropping history** to avoid disease or herbicide carryover.
3. Adequate **soil moisture** or availability of supplemental irrigation.
4. A **dry environment** during seed harvest.
5. Ability to isolate **open or cross-pollinated crops**. For example, self-pollinated tomato plants require only 50 feet of separation between varieties, while some insect- or wind-pollinated crops require up to a mile of separation between varieties to avoid unwanted cross-pollination (65, 98).

Additional requirements for high-quality seed production are the selection of planting density, pest control, and availability of insect pollinators (144). In many cases, conditions for seed production and crop production are very similar.

Woody Plant Seed A number of commercial and professional seed-collecting firms exist that collect and sell seeds of certain timber, ornamental, or fruit species. Lists of such producers are available (36, 88, 90). Such seeds should be properly labeled as to their origin or provenance (see Chapter 5). Some tree seeds can be obtained as certified seeds.

Seed Exchanges. Many arboreta and plant societies have seed exchanges or will provide small amounts of specialty seed.

Seed Collecting. Propagators at individual nurseries may collect tree and shrub seeds (77, 119, 128, 148). These may be collected from specific seed-collection zones or from seed-production areas (see Chapter 5). Seeds may be collected from standing trees, trees felled for logging, or from squirrel caches. They might be collected from parks, roadways, streets, or wood lots. Seed collecting has the advantage of being under the control of the propagator, but requires intimate knowledge of each species and the proper method of handling. Most important, the collector should be aware of the importance of the selection principles described in Chapter 5.

Seed Orchards. Seed orchards or plantations are used to maintain seed source trees of particularly valuable species (23). They are extensively used by nurseries in the production of rootstock seeds of certain species or cultivars and for forest tree improvement. The major advantage to a seed orchard is that it is a consistent

source of seeds from a known (often genetically superior) parentage (90). They also allow the seed producer to maximize seed harvest by reducing loss due to environmental conditions or animals. Such seed orchards are described in Chapter 5.

Fruit-Processing Industries. Historically, many of the fruit tree rootstock seeds were obtained as by-products of fruit-processing industries such as canneries, cider presses, and dry yards. Examples include peach and apricot in California, as well as pears in the Pacific Northwest. The procedure is satisfactory if the correct cultivar is used (see Chapter 5). In some cases, seed-borne viruses might be present in certain seed sources.

HARVESTING AND PROCESSING SEEDS

Maturity and Ripening

Each crop and plant species undergoes characteristic changes leading to seed ripening that must be known to establish the best time to harvest (35, 91, 147, 149). A seed is ready to harvest when it can be removed from the plant without impairing germination and subsequent seed vigor. This is called **harvest maturity**. In many cases, a balance must be made between late and early harvest to obtain the maximum number of high-quality seeds. If harvesting is delayed too long, the fruit may **dehisce**

harvest maturity The time during seed development when the seeds can be harvested for germination without a significant reduction in seed quality.

(“split open” or “shatter”), drop to the ground, or be eaten or carried off by birds or animals. If the fruit is harvested too soon when the embryo is insufficiently developed, seeds are apt to be thin, light in weight, shriveled, poor in quality, and short-lived (34). Some seeds that are mechanically harvested (i.e., sweet corn) can be damaged if the seed moisture at harvest is too dry. Therefore, developing seeds are sampled often to determine their stage of maturity. Seed moisture percentages are used as an indicator of seed maturity to determine the proper harvest time (see Box 6.1). Early seed harvest may also be desirable for seeds of some species of woody plants that produce a hard seed covering in addition to a dormant embryo. If seeds become dry and the seed coats harden, the seeds may not germinate until the second spring (146), whereas they would have germinated the first spring if harvested early.



BOX 6.1 GETTING MORE IN DEPTH ON THE SUBJECT TESTING SEED MOISTURE



Moisture content is found by the loss of weight when a sample is dried under standardized conditions (40). Oven drying at 130°C (266°F) for 1 to 4 hours is used for many kinds of seeds. For oily seeds, 103°C (217°F) for 17 hours is used,

and for some seeds that lose oil at these temperatures (e.g., fir, cedar, beech, spruce, pine, hemlock) a toluene distillation method is used. Various kinds of electronic meters can be used for quick moisture tests (22, 35, 98).

Harvesting and Handling Procedures

Plants can be divided into three types for seed extraction, according to their fruit type:

1. Dry fruits that do not dehisce at maturity
2. Dry fruits that dehisce at maturity
3. Plants with fleshy fruits

Type 1: Dry Fruits That Do Not Dehisce at Maturity

Plants in this group have seed and fruit covers that adhere to each other at maturity. These are dry fruits that do not dehisce (open), and the seeds are not disseminated immediately upon maturity. This group includes most of the agricultural crops, such as corn, wheat, and other grains. Many of these have undergone considerable selection during domestication for ease of harvest and handling. This group also contains the nut crops like oak (*Quercus*), hazel (*Corylus*), and chestnut (*Castanea*).

Field-grown crops (cereals, grasses, corn) can be mechanically harvested using a combine, a machine that

cuts and threshes the standing plant in a single operation (Fig. 6–4). Plants that tend to fall over or “lodge” are cut, piled, or windrowed for drying and curing. Low humidity is important during harvest. Rain damage results in seeds that show low vigor. The force required to dislodge seeds may result in mechanical damage, can reduce viability, and result in abnormal seedlings. Some of these injuries are internal and not noticeable, but they result in low viability after storage (3, 66, 109). Damage is most likely to occur if seed moisture is too high or low, or if the machinery is not properly adjusted. Usually less injury occurs if seeds are somewhat moist at harvest (i.e., up to 45 percent for corn).

Nut crops usually have an involucre covering (i.e., the cup of an acorn) that should be separated from the nut at harvest. Floatation is a common method for separating viable from non-viable seeds (Fig. 6–5, page 168). Floating seeds are more buoyant usually because of insect infestation and are discarded.



Figure 6–4

Corn seed is actually a fruit (caryopsis) and is an example of a crop with dry non-dehiscent fruits. (a) Corn seed is harvested with a picker, leaving the kernels attached to the cob. Although corn used for grain is combined (harvested and shelled in one operation), corn for seed is usually not shelled until it is allowed to dry further to prevent mechanical injury. (b) Corn dehusker. (c) Dehusked corn cobs. (d) Shelled kernels (seeds) ready for storage.

**Figure 6-5**

Non-viable oak nuts (acorns) float in water, while viable seeds are more dense and sink.

Type 2: Dry Fruits That Dehisce at Maturity These plants produce seeds from fruits that dehisce readily at maturity. This type includes seeds in follicles, pods, capsules, siliques, and cones. Crops of this group include many annual or biennial flowers (delphinium, pansy, petunia) (94) and various vegetables (onion, cabbage, other cruciferous crops, and okra). In most cases, these fruits must be harvested before they are fully mature, and then dried or cured before extraction. Consequently, some seeds will be underdeveloped and immature at the time of harvest. For example, in onion seed production there is a difference of up to 20 days between the opening of the first and last flowers on a plant. From a practical standpoint, onion seeds are harvested when the first fruits

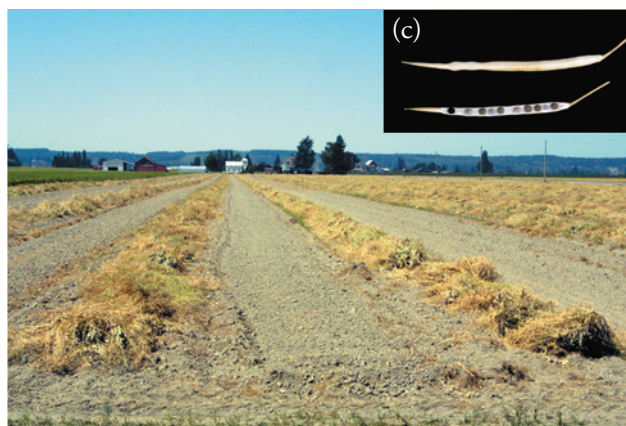
begin to open and seeds have turned black, which corresponds to about 50 days after flowers first open and begin shedding pollen (52).

In addition, many tree and shrub plants also have fruits that fall into this group and are handled with similar procedures. The steps for handling these types of seeds:

1. **Drying.** Plants are cut (sometimes by hand) or dry fruits may be windrowed in the field (Fig. 6-6), or placed on a canvas, tray, or screen (Fig. 6-7) to dry for 1 to 3 weeks. If there are only a few plants, they can be cut and hung upside down in a paper bag to dry. Some crops may need the benefit of forced air drying units for quick dryings, especially in harvest areas with high humidity at the time of harvest (Fig. 6-7).
2. **Extraction.** Commercial seeds may be harvested and extracted in a single operation (Fig. 6-8) with a combine or dried fruits may be passed through threshing machines that extract seeds by beating, flailing, or rolling dry fruit followed by separation of seeds from fruit parts, dirt, and other debris (Fig. 6-9, page 170). Seeds from small seed lots are extracted by hand.
3. **Seed Conditioning (Cleaning).** Further cleaning may be required to eliminate all dirt, debris, weed, and other crop seeds. Commercial seed conditioning (91, 86, 139) utilizes various kinds of specialized equipment, such as screens of different sizes (Fig. 6-10, page 170), seed shape (Fig. 6-11, page 171), air lifters (Fig. 6-12a and b), and gravity separators (Fig. 6-12c and d). The basis for these types of separation is that there are differences in sizes, shapes, and densities between good seed, poor seed, and other debris.



(a)



(b)

**Figure 6-6**

Cole crop (*Brassica*) seed production is also from a dry dehiscent fruit. (a) Turnip at full harvest maturity. (b) Cabbage seed field mowed and windrowed. Windrowing is done before the fruit shatters, and windrowing allows additional maturation and drying before being combined with a windrow pickup unit. (c) Cole crop fruit is a silique, which is a dry, dehiscent fruit that opens along two suture lines, exposing the seeds attached to a papery septum.



(a)



(b)



(c)

Figure 6-7

Seeds with non-dehiscent and dehiscent fruits often require additional drying after harvest. (a) Portable field drying wagons alongside a permanent bin dryer used for drying prairie wildflower seeds. (b) Open wire screen racks used for air drying woody plant seeds. (c) Forced-air dryer.



(a)



(b)



(c)



(d)



(e)



(f)

Figure 6-8

Purple coneflower (*Echinacea*) seed production is an example of crop requiring the dry seed harvesting method. It has a fruit that shatters at maturity. (a) Seed production field in full bloom. (b) Field at harvest maturity before heads shatter and release seeds. (c) Combine for harvesting and threshing seeds. (d) The combine must be calibrated for cutting height and maximum seed retention. (e) The reel rotates and the paddles force plant stems into the (f) blades of the cutting bar.



(a)



(c)



(b)



(d)



(e)

Figure 6-9

Sandersonia seed removal from a dry dehiscent capsule.

(a) Hand-cut fruiting stems are cut and windrowed under protective cover for additional drying. (b) Pods are passed through a threshing machine to remove seeds. (c) The threshing cylinder with a rasp-bar is the most common thresher. (d and e) Proper threshing captures up to 90 percent of the available seeds, but additional conditioning is usually needed to remove fruit debris.



(a)



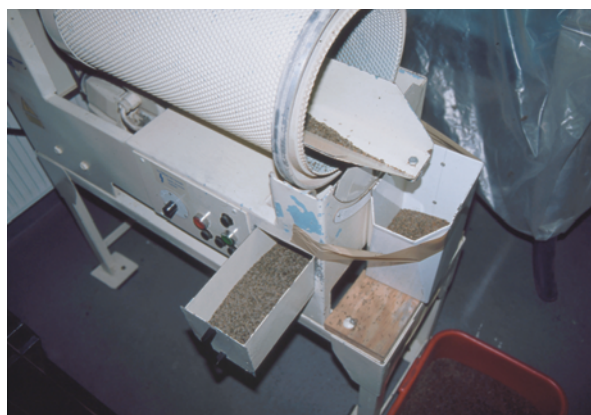
(b)



(c)

Figure 6-10

Seed conditioning based on seed size and shape. (a) Hand screens manually sift seeds from plant debris; (b) Mechanical cleaner and seed sizing units use aspiration (air movement) combined with screens of various shapes and sizes to remove seed debris and separate seeds into various size classes. (c) Close up of screens in a scalper unit that separates good seed from plant debris and other unwanted material.



(a)



(b)

Figure 6-11

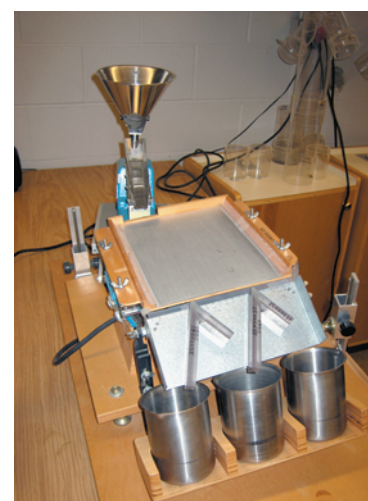
Seed conditioning based on seed shape. (a) An indent cylinder that separates seeds based on seed size (length). (b) A spiral separator uses gravity and centripetal force to separate round from flat seeds. Round seeds move faster down the separator. These are useful for cole crop seeds like cabbage and broccoli.



(a)



(b)



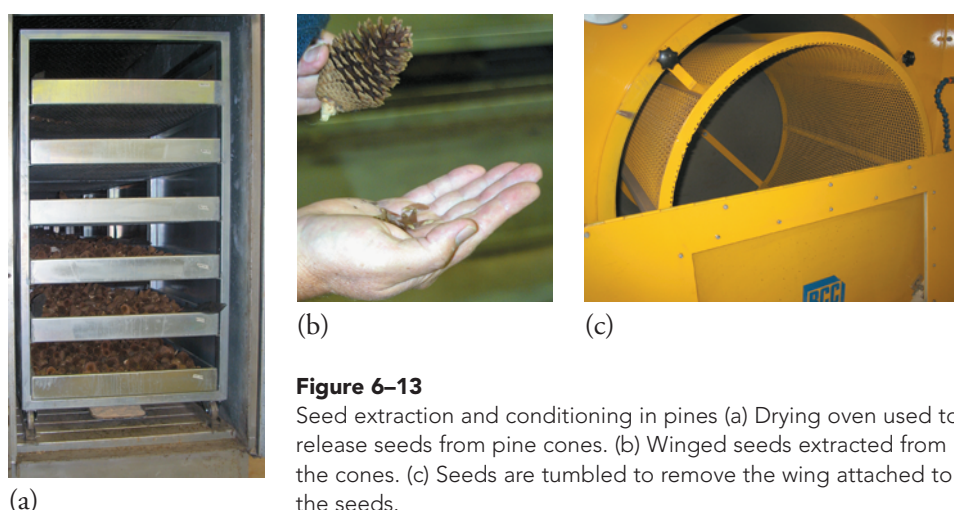
(c)



(d)

Figure 6-12

Seed conditioning based on seed density. (a) The wall mounted air separator uses a vacuum to lift seeds. Seeds are separated from lighter plant debris. (b) Standalone movable air separator. (c and d) Gravity tables have a tilted platform that uses vibration or air flow to separate seeds. Denser seeds walk toward the higher edge of the platform. Both types of units can be used to upgrade seed lots by directing seeds into bins based on density (weight).

**Figure 6-13**

Seed extraction and conditioning in pines (a) Drying oven used to release seeds from pine cones. (b) Winged seeds extracted from the cones. (c) Seeds are tumbled to remove the wing attached to the seeds.

Conifer cones also fit in this category of dry dehiscent fruits, but their cones require special procedures (119):

1. **Drying.** Cones of some species will open if dried in open air for 2 to 12 weeks (Fig. 6-13). Others must be force-dried at higher temperatures in special heating kilns. Under such conditions, cones will open within several hours or, at most, 2 days. The temperature of artificial drying should be 46 to 60°C (115 to 140°F), depending upon the species, although a few require even higher temperatures. For example, Jack pine (*Pinus banksiana*) and red pine (*P. resinosa*) need high temperatures (77°C to 170°F) for 5 to 6 hours. Caution must be used with high temperatures, because overexposure will damage seeds. After the cones have been dried, the scales open, exposing the seeds.
2. **Extraction.** Seeds should be removed immediately upon drying, since cones may close without releasing the seeds. Cones can be shaken by tumbling or raking to dislodge seeds. A revolving wire tumbler or a metal drum is used when large numbers of seeds are to be extracted.
3. **Dewinging.** Conifer seeds have wings that are removed except in species whose seed coats are easily injured, such as incense cedar (*Calocedrus*). Fir (*Abies*) seeds are easily injured, but wings can be removed if the operation is done gently. Redwood (*Sequoia* and *Sequoiadendron*) seeds have wings that are inseparable from the seed. For small seed lots, dewinging can be done by rubbing the seeds between moistened hands or trampling or beating seeds packed loosely in sacks. For larger lots of seeds, special dewinging machines are used (Fig. 6-13c).

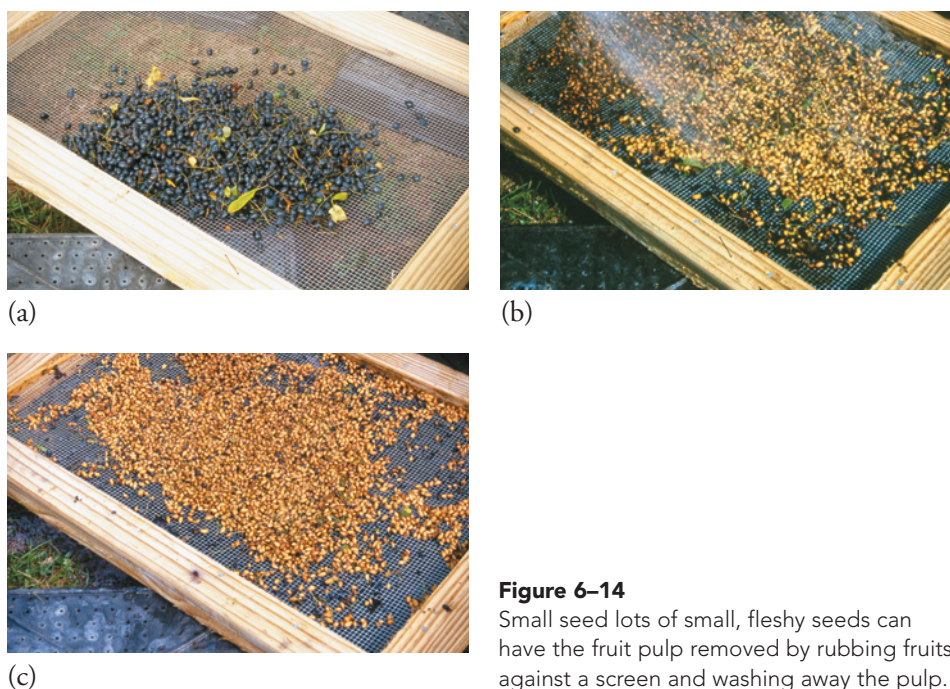
4. **Cleaning.** Seeds are cleaned after extraction to remove wings and other light chaff. As a final step, separation of heavy, filled seed from light seed is accomplished by gravity or pneumatic separators.

Type 3: Plants with Fleshy Fruits Plants with fleshy fruits include important fruit and vegetable species used for food such as berries, pomes (apples), and drupes (plums), as well as many related tree and shrub species used in landscaping or forestry. In general, fleshy fruits are easiest to handle if ripe or overripe. However, fruits in the wild are subject to predation by birds (45).

For **extraction** of small seed lots, fruits may be cut open and seeds scooped out, treaded in tubs, rubbed through screens, or washed with water from a high-pressure spray machine in a wire basket (Fig. 6-14). Another device that removes seeds from small-seeded fleshy fruits is an electric mixer or **blender** (Fig. 6-15) (122). To avoid injuring seeds, the metal blade of the blender can be replaced with a piece of rubber or Tygon tubing. It is fastened at right angles to the revolving axis of the machine (147). A mixture of fruits and water is placed in the mixer and stirred for about 2 minutes. When the pulp has separated from the seed, the pulp is removed by flotation. This procedure is satisfactory for fruits of serviceberry (*Amelanchier*), barberry (*Berberis*), hawthorn (*Crataegus*), strawberry (*Fragaria*), huckleberry (*Gaylussacia*), juniper (*Juniperus*), rose (*Rosa*), and others (122).

For larger lots, separation is by maceration, fermentation, mechanical means, or washing through screens. The basic procedures include:

1. **Maceration.** Vegetable crops such as tomato, pepper, eggplant, and various cucurbits are produced in commercial fields and may utilize special macerating machinery as a first step in seed extraction (126).

**Figure 6-14**

Small seed lots of small, fleshy seeds can have the fruit pulp removed by rubbing fruits against a screen and washing away the pulp.

Cucumber and other vine crops, for example, are handled with specially developed macerating machines (Fig. 6-16, page 174). Maceration crushes the fruits and mixes the pulverized mass with water that is diverted into a tank releasing the seeds, but

additional handling is often required to separate seeds from the macerated pieces of fruit.

2. **Fermentation.** Macerated fruits can be placed in large barrels or vats and allowed to ferment for up to 4 days at about 21°C (70°F), with occasional stirring.

**Figure 6-15**

A method for small batch extraction of seeds from fleshy fruits uses a blender (a) or food processor retrofitted with a rubber or plastic impeller for maceration followed by floatation (b and c) to remove seeds from the pulp. (d) Commercial macerators (i.e., Dybvig) use the same principles of water and flailing impellers to extract seeds. They work well for fruit crops like cherry, peach, and plum.



(a)



(b)



(c)



(d)



(e)



(f)

Figure 6-16

Watermelon is an example of a crop that requires the wet seed harvesting method for seed extraction from a fleshy fruit. (a) Field ready for harvest. Withholding water knocks down the vines prior to harvest. (b) Custom seed harvester for large fleshy fruit. (c) Fruit is crushed and the pulp is separated from the seeds. (d) Seeds with a small amount of adhering pulp. (e) A washing unit provides final separation of pulp and seeds. (f) Large rotating dryers reduce seed moisture to its storage level.

If the process is continued too long, sprouting of the seeds may result. Higher temperature during fermentation shortens the required time. As the pulp separates from seeds, heavy, sound seeds sink to the bottom of the vat, and the pulp remains at the surface. Following extraction, the seeds are washed and dried either in the sun or in dehydrators. Additional cleaning is sometimes necessary to remove dried pieces of pulp and other materials. Extraction by fermentation is particularly desirable for tomato seed, because it can help control bacterial canker (35, 89).

3. **Chemical Treatment.** Alternatives to fermentation are various chemical treatments. The advantage of chemical treatments is that it takes less time (less than 24 hours) to separate seeds from macerated pulp. Like fermentation, overexposure to the chemical can reduce seed quality. Chemical treatments include acid treatment for tomato seed extraction (98), and

digestive enzymes—like pectinase used in orange seed extraction—for understock production (12).

4. **Flotation.** Another alternative to separate seeds from fleshy fruits is floatation, which involves placing seeds and pulp in water so that heavy, sound seeds sink to the bottom and the lighter pulp, empty seeds, and other extraneous materials float to the top. This procedure can also be used to remove lightweight, unfilled seeds and other materials from dry fruits, such as acorn fruits infested with weevils, but sometimes both good and bad seeds will float. Small berries of some species, such as *Cotoneaster*, juniper (*Juniperus*), and *Viburnum*, are somewhat difficult to process because of small size and the difficulty in separating the seeds from the pulp. One way to handle such seeds is to crush the berries with a rolling pin, soak them in water for several days, and then remove the pulp by flotation.



(a)



(b)

Figure 6-17

Various drying units for seeds. (a) A spinning centripetal dryer. (b) A large rotating forced air dryer.

After seeds are thoroughly washed to remove fleshy remnants, they are dried (Fig. 6-17), except seeds of recalcitrant species that must not be allowed to dry out. If left in bulk for even a few hours, seeds that have more than 20 percent moisture will heat; this impairs viability. Drying may either occur naturally in open air if the humidity is low or artificially with heat or other devices. Drying temperatures should not exceed 43°C (110°F); if the seeds are quite wet, 32°C (90°F) is better. Drying too quickly can cause seeds to shrink and crack, and can sometimes produce hard seed coats. The minimum safe moisture content for storage of most orthodox seeds differs by species but is usually in the range of 4 percent to 15 percent.

SEED TESTING

In the United States, state laws regulate the shipment and sale of agricultural and vegetable seeds within each state. Seeds entering interstate commerce or those sent

from abroad are subject to the **Federal Seed Act**, adopted in 1939. Such regulations require the shipper to use labeling (Fig. 6-18) of commercially produced seeds that includes:

1. Name and cultivar
2. Origin
3. Germination percentage
4. Percentage of pure seed, other crop seed, weed seed, and inert material

Regulations set minimum standards of quality, germination percentage, and freedom from weed seeds. Special attention must be paid to designated **noxious weeds** for a particular growing region. Laws in some states (117) and in most European countries regulate shipment and the sale of tree

noxious weeds

Weeds that vary from state to state, but that have been designated as weed species that must be identified in the seed lot and may cause the whole seed lot to be unsaleable.

Form A—For Unmixed Alfalfa, Clovers or Grasses

Lot _____ Seedman _____
 Address _____
 Kind _____ Variety _____
 Pure Seed _____ % Germination _____ %
 Inert Matter _____ % Hard Seed _____ %
 Crop Seed _____ % Date of Test _____ 19____
 Weed Seed _____ % Where Grown _____
 See other side for noxious weed seed list

PROHIBITED NOXIOUS WEED SEEDS

Balloosvine (*Carduus arvensis*)
 Canada Thistle (*Cirsium arvense*)
 Johnsongrass (*Sorghum halepense*) and
 Sorghum alatum
 Purple Moonflower (*Limonium tomentosum*)
 Quackgrass (*Agropyron repens*)

RESTRICTED NOXIOUS WEED SEEDS
 IF PRESENT, NUMBER PER POUND

Annual Bluegrass (*Poa annua*)
 Buckhorn Plantain (*Plantago lanceolata*)
 Corncockle (*Agrostemma githago*)
 Dodder (*Cuscuta* spp.)
 Giant Foxtail (*Setaria faberii*)
 Ox-eye Daisy (*Chrysanthemum*
leucanthemum)
 Sorrel (*Rumex acetosella*)
 Wild Onion and Wild Garlic (*Allium* spp.)

Figure 6-18

State and federal seed laws require testing seed lots prior to sale. Information for a seed lot includes standard germination percentage according to accepted seed-testing rules, purity of the seed lot (percentage of seeds that are the desired crop and its trueness to type), percentage of weed seeds, and the amount of noxious weed seeds in the seed lot. Noxious weeds are designated as weeds that are particularly undesirable, and tolerances may differ for a crop or region of the country.

seed, but there are no federal laws governing the tree seed trade.

Seed testing provides information in order to meet legal standards, determines seed quality (39), and establishes the rate of sowing for a given stand of seedlings (37). It is desirable to retest seeds that have been in storage for a prolonged period.

Procedures for testing agriculture and vegetable seeds in reference to the Federal Seed Act are given by the U.S. Department of Agriculture. The most current version of the Federal Seed Act can be found at the U.S. Electronic Code of Federal Regulations (53). The **Association of Official Seed Analysts, Inc.** (www.aosaseed.com), (5) publishes the “rules” for seed testing for the major edible food crops as well as many ornamental plant species. International rules for testing

seed testing associations

Organizations that set the standards for seed testing and can also train and certify seed analysts.

seeds are published by the **International Seed Testing Association** (www.seedtest.org) (73). The Western Forest Tree Seed Council also publishes testing procedures for tree seed and other

useful information in their online woody plant seed manual (www.nsl.fs.fed.us/wpsm).

A high-quality seed lot is a function of the following characteristics that are routinely tested by seed companies or private and state seed labs (116):

1. Germination (viability)
2. Purity
3. Vigor
4. Seed health
5. Noxious weed seed contamination

Sampling for Seed Testing

The first step in seed testing is to obtain a uniform sample that represents the entire lot under consideration (Fig. 6–19). Equally sized (usually measured by weight) primary samples are taken from evenly distributed parts of the seed lot, such as a sample from each of several sacks in lots of less than five sacks or from every fifth sack with larger lots. The seed samples are thoroughly mixed to make a composite sample. A representative portion is used as a submitted sample for testing. This sample is further divided into smaller lots to produce a working sample (i.e., the sample upon which the test is actually to be run). The amount of seed required for the working sample varies with the kind of seed and is specified in the Rules for Seed Testing (5).



Figure 6–19

A sample from each seed lot must be tested prior to sale usually by a state-certified seed lab. The seed analyst uses a seed sorter to randomly select a seed sample for testing from the submitted seed lot. A portion of the seed lot will be tested for purity, while an additional subsample will be evaluated for standard germination.

Viability Determination

Viability can be determined by several tests, the **standard germination**, **excised embryo**, and **tetrazolium** tests being the most important.

Standard Germination Tests

In the standard germination test, germination percentage is determined by the percent of **normal seedlings** produced by pure seeds (the kind under consideration). To produce a good test, it is desirable to use at least 400 seeds picked at random and divided into lots of 100 each. If any two of these lots differ by more than 10 percent, a retest should be carried out. Otherwise, the average of the four tests becomes the official germination percentage. Seeds are placed under optimum environmental conditions of light and temperature to induce germination. The conditions required to meet legal standards

standard germination

The most common test for seed quality. It is performed according to standards set by seed-testing associations, often by certified seed analysts. It represents the percentage of seedlings in a seed lot that germinate normally. In a standard germination test, only seeds that are normal are counted as germinated.

normal seedlings

Seedlings described for the major crops (often in pictures) in the rules for seed testing. In general, normal seedlings have elongated radicle and hypocotyl and at least one enlarged cotyledon.



are specified in the rules for seed testing, which may include type of test, environmental conditions, and length of test (5, 73).

Various techniques are used for germinating seeds in seed-testing laboratories (127). Small seeds are placed on plastic germination trays or in Petri dishes (Fig. 6–20). The most common substrate used by commercial seed technology labs for germination tests are blue blotter or washed paper towels, available from commercial suppliers. These products ensure uniformity and reproducibility in their tests. Containers are placed in germinators in which temperature, moisture, and light are controlled according to the established standard germination rules. To discourage the growth of microorganisms, all materials and equipment should be kept scrupulously clean, sterilized when possible, and the water amount carefully regulated.

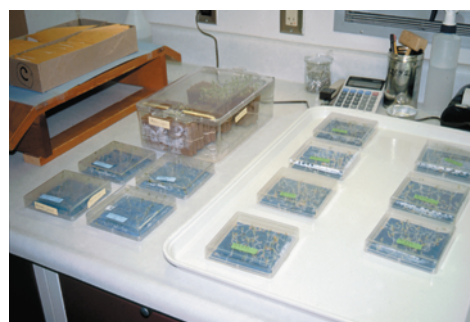
The **rolled towel test** (Fig. 6–21a, b, and c, page 178) is commonly used for testing large seeds like cereal grains. Several layers of moist paper toweling, about 2.8 by 3.6 cm (11 by 14 in) in size, are folded over the seeds and then rolled into cylinders and placed vertically in a germinator.

A germination test usually runs from 1 to 4 weeks but could continue up to 3 months for some slow-germinating tree seeds with dormancy. Usually a first

count is taken at 1 week and germinated seeds are discarded with a final count taken later. At the end of the test, seeds are divided into (a) normal seedlings, (b) hard seeds, (c) dormant seeds, (d) abnormal seedlings, and (e) dead or decaying seeds. A normal seedling should have a well-developed root and shoot, although the criterion for a “normal seedling” varies with different kinds of seeds (Fig. 6–21d). “Abnormal seedlings” can be the result of age of seed or poor storage conditions; insect, disease, or mechanical injury; frost damage; or mineral deficiencies. Any non-germinated seeds should be examined to determine the possible reason. “Hard seeds” have not absorbed water. Dormant seeds are those that are firm, swollen, and free from molds but do not germinate.

Under seed-testing rules, certain environmental requirements to overcome dormancy may be specified routinely for many kinds of seeds (5, 73). These may include chilling stratification or hormone treatment with gibberellins or potassium nitrate.

Excised-Embryo Test The excised-embryo test is used to test seed viability of woody shrubs and trees whose dormant embryos require long treatment periods to relieve dormancy before true germination will take



(a)



(b)



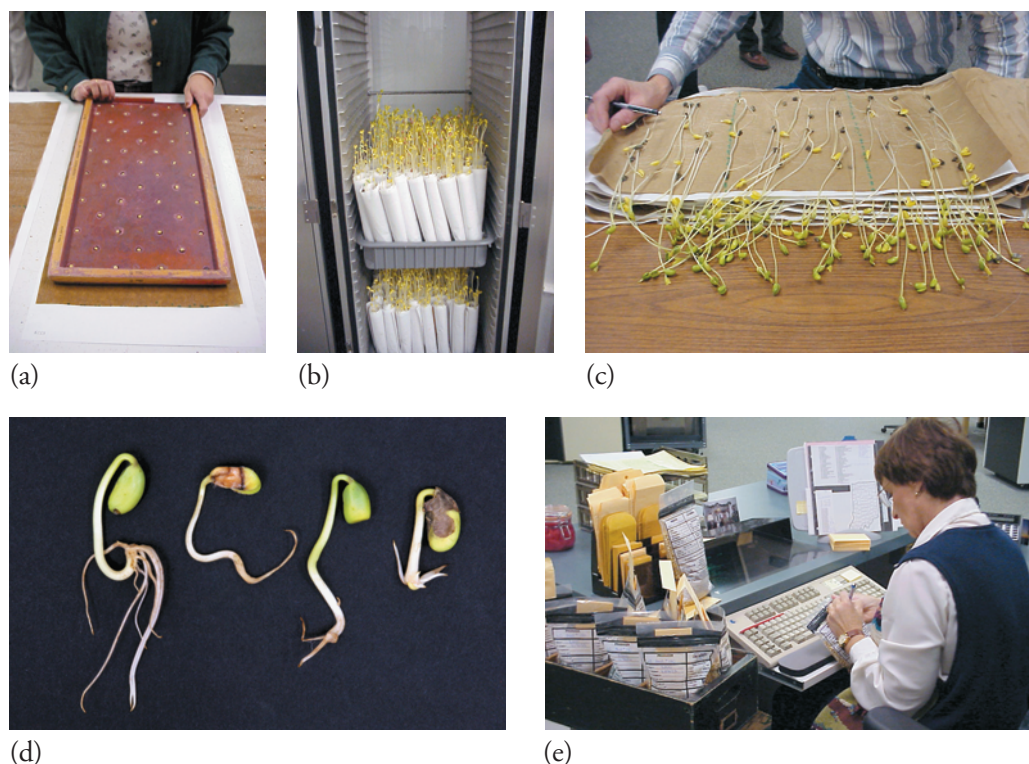
(c)



(d)

Figure 6–20

A standard germination test is required for seed lots prior to sale. The two most common test procedures include the (a, b, and c) Petri dish and (d) rolled towel tests. The tests and the procedures used for standard germination are detailed in accepted publications like the rules for testing seeds from the Association of Official Seed Analysts (4, 5). Included in these rules will be the preferred test (i.e., Petri dish or rolled towel); the environment for the test (i.e., 20/30, this indicates daily cycles of 16 hours at 20°C followed by 30°C for 8 hours); whether light is required during the test; any seed pretreatments for dormant seeds (e.g., treatment with gibberellin or potassium nitrate); and the number of days for the first and last evaluation (counts).

**Figure 6-21**

Commercial seed labs process a large number of seed samples. They must keep accurate records of each seed lot and must be efficient to process samples in a timely manner while maintaining high reproducibility from seed lot to seed lot. (a) A seed analyst uses a template board to place a standard number of seeds in precise locations on the germination paper for the rolled towel or Petri dish tests. (b) Rolled towels are held upright in the growth chamber. (c) After the number of days indicated in the testing rules, the seed analyst counts the number of normal seedlings. (d) The seed analyst must determine if a seedling is normal and can be counted as germinated. These seedlings are "abnormal" because either the shoot or root has not developed normally after the final count for this seed test. (e) Results are recorded in a computer database.

place (5, 44, 67). In this test, the embryo is excised from seeds that are soaked for 1 to 4 days and germinated following standard germination conditions (see Fig. 6-22).

The excision must be done carefully to avoid injury to the embryo. Any hard, stony seed coverings, such as the endocarp of stone fruit seeds, must be removed first. The moistened seed coats are cut with a sharp scalpel, razor blade, or knife, under clean but nonsterile conditions with sterilized instruments. The embryo is carefully removed. If a large endosperm is present, the seed coats may be slit and the seeds covered with water, and after about a half-hour, the embryo may float out or be easily removed.

Tetrazolium Test The **tetrazolium test** (6) is a biochemical test for viability determined by the red color appearing when seeds are soaked in a 2,3,5-triphenyl-tetrazolium chloride (TTC) solution (Fig. 6-23).

Living tissue changes the TTC to an insoluble red compound (chemically known as formazan); in non-living tissue the TTC remains uncolored. The test is positive in the presence of dehydrogenase enzymes involved in respiration. This test was developed in Germany by Lakon (87), who referred to it as a **topographical test** since loss in embryo viability begins to appear at the extremity of the radicle, epicotyl, and cotyledon tips. The reaction takes place equally well in dormant and nondormant seed. Results can usually be obtained within 24 hours (see Box 6.2, page 180). The TTC solution deteriorates with exposure to light but will remain in good condition for several months if stored in a dark bottle. The solution should be discarded if it becomes yellow. A 0.1 to 1.0 percent concentration is commonly used. The pH should be 6 or 7. In the hands of a skilled technologist, this test can be used for seed-quality evaluation and as a tool in seed research (101).

**Figure 6-22**

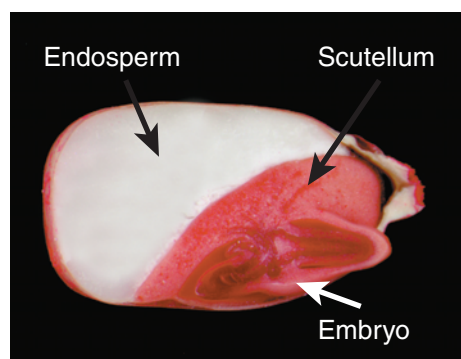
The excised-embryo test is a quick evaluation method used for dormant seed. Eastern redbud (*Cercis*) seeds require at least four months of moist chilling to satisfy dormancy and another 2 weeks for a standard germination test. In comparison, isolated embryos removed from the seed coverings will germinate in 5 days.

X-ray Analysis X-ray analysis of seeds (80) can be used as a rapid test for seed soundness (2). X-ray photographs do not normally measure seed viability but provide an examination of the inner structure for mechanical disturbance, absence of vital tissues, such as embryo or endosperm, insect infestation, cracked or broken seed coats, and shrinkage of interior tissues (Fig. 6-24).

Standard X-ray equipment is used to assess seeds. Dry seeds are exposed for ½ to 3 minutes at 15- to 20-kilovolt tube potential. Seed with dimensions less than 2 mm are too small to show details. Since X-rays do not injure the seed, further tests for viability can be conducted on the same batch (2). Prototype machines that provide fast, automatic, online sorting have been proposed (140). These procedures have the potential to remove nonviable seeds as well as seeds with morphological characteristics that are linked to poor vigor.



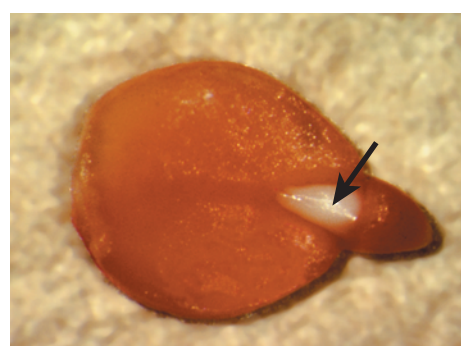
(a)



(b)



(c)



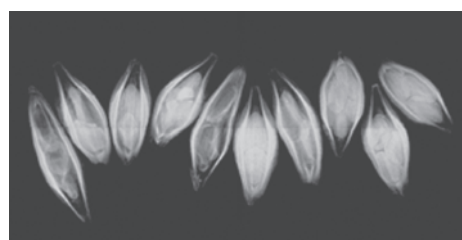
(d)

Figure 6-23

Tetrazolium chloride (TZ) is used to test seed viability. Portions of the embryo will stain red (an indication of respiration) if they are viable. The seed analyst must determine if vital portions of the embryo are living, which would indicate positive germination potential. (a and b) A positive TZ corn seed test showing that the embryo and scutellum are viable while the white endosperm is non-living at maturity. (c and d) A poor TZ test in gasplant (*Dictamnus*). White embryos are non-viable and the embryo (d) although generally red-stained would probably be abnormal because the shoot area (arrow) did not stain.



(a)



(b)

Figure 6-24

Examples of the X-ray tests for the 1999 (a) and 2005 (b) harvests of *Gaura biennis* capsules. Note the number of filled and empty (aborted) seeds in the capsules. Courtesy of the Ornamental Plant Germplasm Center, The Ohio State University.



BOX 6.2 GETTING MORE IN DEPTH ON THE SUBJECT TETRAZOLIUM TESTING



Details vary for different seeds, but general procedures include (6, 73, 127):

1. Any hard covering such as an endocarp, wing, or scale must be removed. Tips of dry seeds of some plants, such as *Cedrus*, should be clipped.
2. First, seeds should be soaked in water in the dark; moistening activates enzymes and facilitates the cutting or removal of seed coverings. Seeds with fragile coverings, such as snap beans or citrus, must be softened slowly on a moist medium to avoid fracturing.
3. Most seeds require preparation for TTC absorption. Embryos with large cotyledons, such as *Prunus*, apple, and pear, often comprise the entire seed, requiring only seed coat removal. Other kinds of seed are cut longitudinally to expose the embryo (corn and large-seeded grasses, larch, some conifers); or transversely one-fourth to one-third at the end away from the radicle (small-seeded grasses, juniper, *Carpinus*, *Cotoneaster*, *Crataegus*, *Rosa*, *Sorbus*, *Taxus*). Seed coats can be removed, leaving the large endosperm intact (some pines, *Tilia*). Some seeds (legumes, timothy) require no alteration prior to the tests.
4. Seeds are soaked in the TTC solution for 2 to 24 hours. Cut seeds require a shorter time; those with exposed embryos somewhat longer; intact seeds 24 hours or more.
5. Interpretation of results depends on the kind of seed and its morphological structure. Completely colored embryos indicate good seed. Conifers must have both the megagametophyte and embryo stained. In grass and grain seeds, only the embryo itself colors, not the endosperm. Seeds with declining viability may have uncolored spots or be unstained at the radicle tip and the extremities of the cotyledons. Nonviability depends on the amount and location of necrotic areas, and correct interpretation depends on standards worked out for specific seeds (127).
6. If the test continues too long, even tissues of known dead seeds become red due to respiration activities of infecting fungi and bacteria. The solution itself can become red because of such contamination.

Purity Determination

purity A determination assessed in a seed lot by a seed analyst who is certified for purity tests. It involves meticulous evaluation of a seed lot for any foreign material including seeds.

Purity is the percentage by weight of the “pure seed” present in a sample. Purity determination requires a trained seed analyst, usually from a state or private seed lab. In the United States, the **Society of**

Commercial Seed Technologists provides training and testing to certify **Registered Seed Technologists** (116).

There are two aspects to pure seed: a **physical** and a **genetic** component (4, 116). Pure seed must be separated from other physical contaminants such as soil particles, plant debris, other inert material, and weed seeds (Fig. 6–25). Seed standards list tolerances for levels of pure seed in a sample. They usually are based on the seed type and seed class (i.e., Certified vs. Registered seed—see Chapter 5). References are available with detailed seed anatomy to help seed technologists to identify crop and weed seeds (18). Special care must be taken to document the occurrence of noxious weeds in a sample. **Noxious weeds** are identified as being particularly bad weeds for a region of the country and can vary by state. Occurrence of a single seed of some noxious weed

species in a sample can render an entire seed lot unacceptable for public sale.

Purity testing also identifies the genetic purity of a seed lot. The seed analyst determines if the sample is the proper cultivar and identifies the percentage of seeds that are either other contaminating cultivars or inbreds in a hybrid seed lot (see Chapter 5). Genetic purity can be difficult to determine and relies on an assortment of tests that include field visits by regulatory personnel, seed color, seed and seedling morphology, chemical tests, isozyme (characteristic seed proteins) separation by electrophoresis (4, 116), and DNA fingerprinting (99) (see Box 6.3).

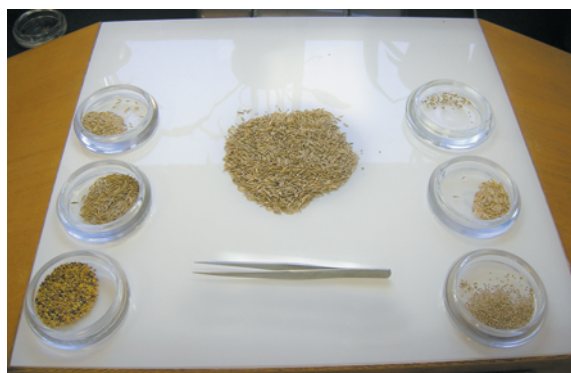
Vigor Testing

Although state and federal seed laws currently require only purity and standard germination tests for seed lots, seed companies and many crop producers are performing **vigor** tests prior to sale or use (95). The Association of Official

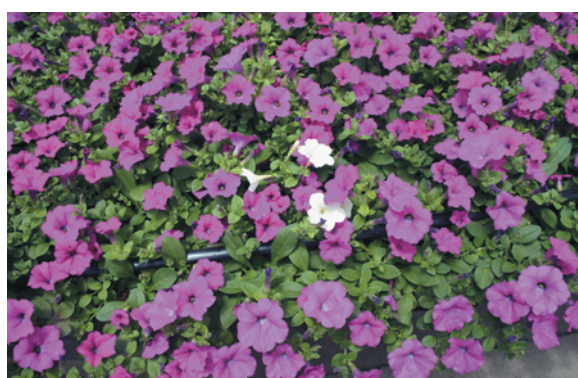
vigor (of a seed lot)
An estimate of the seed’s ability to germinate when the environmental conditions are not ideal for germination. Seed lots with high vigor show a high germination percentage and uniform seedling emergence.



(a)



(b)



(c)

Figure 6-25

Purity of seeds is determined by visual examination of individual seeds in a weighed seed sample taken from the larger lot in question. (a) Impurities may include other crop seed, weed seed, and inert, extraneous material. In this seed lot, several different types of impurities were discovered in the seed lot. (b) Each was placed in a small dish and will be weighed. (c) Purity is also evaluated in field or greenhouse trials. This petunia seed lot shows a percentage of white variants reducing its purity. White plants may be from self-pollinated plants from the female inbred parent that should have been removed during production.

BOX 6.3 GETTING MORE IN DEPTH ON THE SUBJECT TESTS FOR GENETIC PURITY



Details for cultivar identification are published in the Association of Official Seed Analysts' handbook for purity testing (4). These can include:

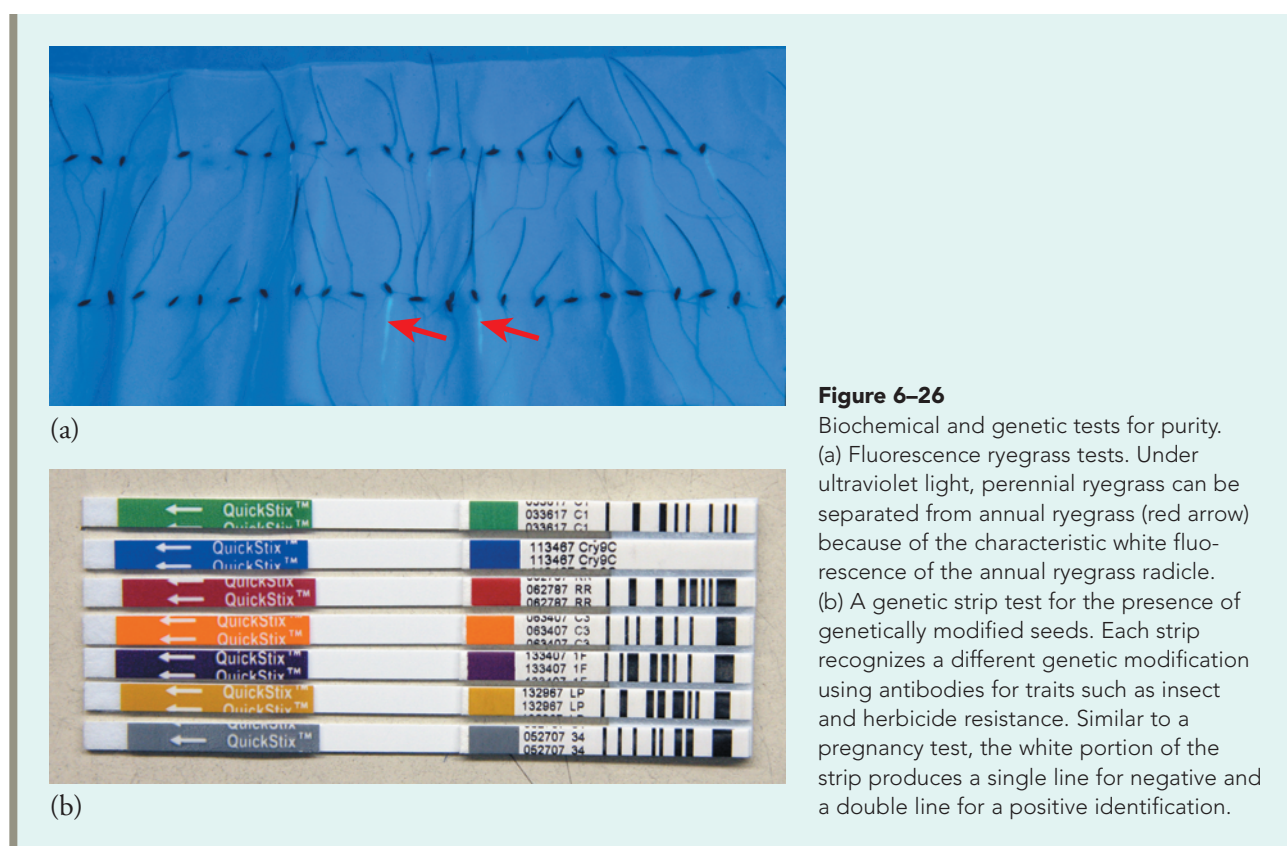
Chemical Tests There are a number of chemical treatments used to separate cultivars of specific species (31). Examples include a fluorescence test for fescue and ryegrass (Fig. 6-26a), hydrochloric acid for oat, and peroxidase for soybean. The chemical reaction usually gives a characteristic color that identifies the seed. Chemical tests are usually used in association with other tests, like seed shape and color, to help determine purity.

Protein Electrophoresis A more sophisticated evaluation for cultivar identification uses differences that exist in seed proteins or enzymes. Some plant enzymes are present in different forms (isozymes) that can be separated by electrophoresis to give a pattern that is characteristic of a cultivar. Electrophoresis is a form of chromatography that uses an electrical current to separate proteins on a gel. Isozymes migrate to different locations on the gel to form a pattern that identifies the cultivar.

DNA Fingerprinting This technique also uses the basic principle of electrophoresis but separates fragments of DNA such as RAPDs (random amplified polymorphic DNA), RFLPs (random fragment length polymorphisms) and SCARs (sequence-characterized amplified region) rather than proteins (99). Since these techniques use amplified DNA, the test is very accurate and can identify a larger number of cultivars than can isozyme analysis. DNA fingerprinting is the same process being used by law enforcement to identify suspects in criminal cases.

Strip Tests for Genetically Modified Organisms (GMOs) The presence of specific GMO seeds can be detected using commercially available strip tests that identify the presence of an antibody for the genetically modified trait (Fig. 6-26b). For example, Bt corn is genetically transformed to produce *Bacillus thuringiensis* proteins (Cry1Ab and Cry1Ac) that are toxic to caterpillars. The strip test contains antibodies to the Bt proteins. If the extract from the seed sample contains these proteins, they will react with the strip's antibodies and produce a double-lined color reaction.

(Continued)

**Figure 6-26**

Biochemical and genetic tests for purity.

(a) Fluorescence ryegrass tests. Under ultraviolet light, perennial ryegrass can be separated from annual ryegrass (red arrow) because of the characteristic white fluorescence of the annual ryegrass radicle.

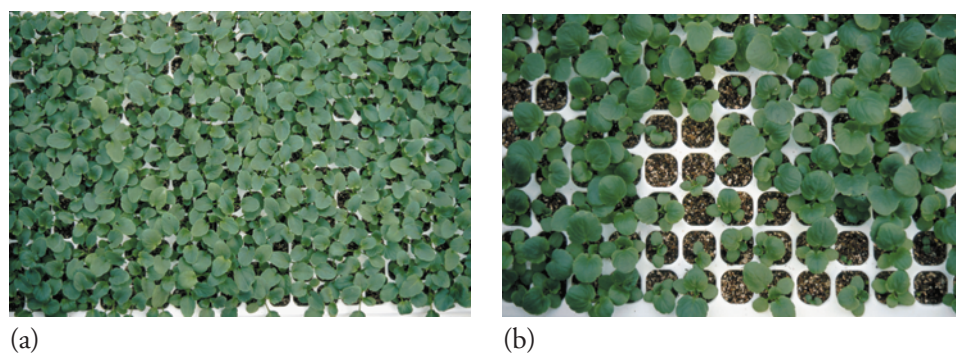
(b) A genetic strip test for the presence of genetically modified seeds. Each strip recognizes a different genetic modification using antibodies for traits such as insect and herbicide resistance. Similar to a pregnancy test, the white portion of the strip produces a single line for negative and a double line for a positive identification.

Seed Analysts (7) states that “seed vigor comprises those seed properties which determine the potential for rapid, uniform emergence, and development of normal seedlings under a wide range of field conditions.” Standard germination tests do not always adequately predict seedling emergence under field conditions (Fig. 6-27). Seed vigor tests can provide a grower with additional information that can help predict germination where conditions may not be ideal (110). For many vegetable crops, there is a positive relationship between seed vigor and crop yields (38, 85, 135). Various vigor tests have been developed and certain tests are applied to different species (49). Vigor tests include accelerated aging, controlled

deterioration, cold test, cool test, electrolyte leakage, seedling growth rate, and seedling grow-out tests (5, 58, 73, 116) (see Box 6.4).

Seed Health (1)

Seed companies usually have the personnel and facilities to evaluate the health of a seed lot. Seed health comprises the occurrence of diseases, insects, or nematodes in the seed lot (70, 93). Detection of these organisms requires specialized equipment and trained personnel. Seed health is integral to the performance of the seed lot. It has also become increasingly important as international trading agreements (like the World Trade Organization and the North American Free

**Figure 6-27**

Here is a good example of the impact of seed vigor on stand establishment. In both cases, all pansy seeds have germinated in each plug flat, but seedlings on the left (a) are all at the same stage of growth, while the plug flat on the right (b) has numerous seedlings that are less developed than the majority of seedlings.



BOX 6.4 GETTING MORE IN DEPTH ON THE SUBJECT SEED VIGOR TESTS



Details for procedures used to conduct vigor tests are found in the Association of Official Seed Analysts' handbook on seed vigor testing (7). The more commonly conducted vigor tests include (Fig. 6–28).

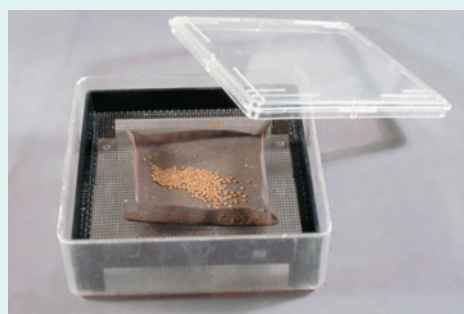
Aging Tests Controlled deterioration and accelerated aging (AA) are established vigor tests for agronomic, horticultural, and forestry species. Both tests are based on the premise that vigor is a measure of **seed deterioration**. Hampton and Coolbear (60) concluded that aging tests were the most promising vigor tests for most agronomic species. Both methods are described in detail in the AOSA vigor testing methods (59).

Seed deterioration The loss of vigor and viability in a seed during storage.

Controlled deterioration (92) exposes seeds to high temperature (40 or 45°C) for a short duration (24 or 48 hours)

after the moisture content has been raised to approximately 20 percent. Seed moisture is raised prior to exposure to high temperature and maintained by keeping seeds in sealed watertight packages. Germination is usually assessed as radicle emergence, but normal germination improves results in some cases.

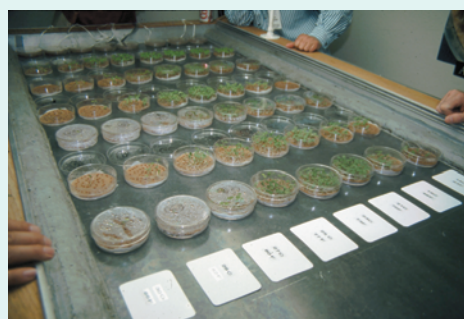
Accelerated aging is similar to controlled deterioration but differs in the way seed moisture is increased and, therefore, modifies the duration of the test (133). It is a test commonly used for agronomic and vegetable seeds. Prior to a standard germination test, seeds are subjected to high temperatures (40 to 45°C) and high relative humidity (near 100 percent) for 2 to 5 days. This is done by suspending seeds on a stiff nylon frame suspended above water in specially designed boxes (Fig. 6–28a). This partially hydrates the seed without permitting radicle emergence. Higher-vigor seeds tolerate this stress better than



(a)



(b)



(c)



(d)

Figure 6–28

Various seed vigor tests. (a) Impatiens seeds in accelerated aging boxes. The frame inside the box keeps seeds suspended above water or a solution of saturated salts. (b) Sweet corn seeds sprouting in the cold test. Seeds are placed on moist towels or Kimpack and covered with field soil. It is easy to see that the seed lot on the *left* has higher vigor (seedling emergence) compared with the seed lot on the *right*. (c) A thermal gradient table provides numerous temperatures to simultaneously test germination of a single seed lot, which is useful for determining seed vigor by evaluating germination at minimal and maximal temperatures. Breeders also use thermal gradient tables to evaluate a genotype's tendency for producing seed susceptible to thermodormancy (like lettuce). (d) For many horticultural crops, standard germination and seedling vigor is evaluated in a seedling grow-out test. The environment for this test is standard greenhouse conditions where the crop will be commercially grown.

(Continued)



low-vigor seeds, as shown by higher normal germination percentages in the standard germination test conducted after the aging treatment. For smaller-seeded species, like flower seeds, lower relative humidity is used to reduce rapid seed hydration. This variation is called the saturated salt accelerated aging test, because it uses saturated salts rather than water to control humidity in the accelerated aging boxes (150).

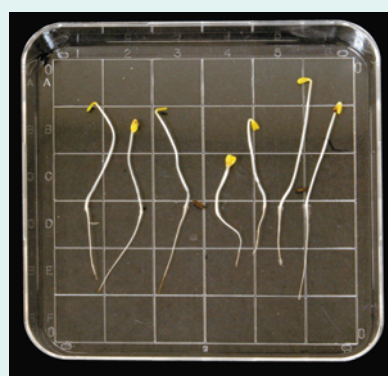
Cold Test (59) This is the preferred vigor test for corn seed (Fig. 6–28b). Seeds are planted in boxes, trays, or rolled towels that contain field soil and held at 10°C for 7 days before being moved to 25°C. The number of normal seedlings that emerge are counted after 4 days.

Cool Test This is a vigor test that uses procedures identical to the standard germination test, except the temperature is lowered to 18°C. A similar tool being used to evaluate vegetable and flower seed vigor is the thermal gradient table (Fig. 6–28c). This provides a range of temperatures by circulating warm and cold water to the table. This determines the range of germination for a seed lot. Higher vigor seeds germinate better at the extreme temperatures on the table.

Electrolyte Leakage Seeds tend to “leak” electrolytes when imbibed, and the amount of electrolyte leakage

usually increases as seeds deteriorate. Electrical conductivity can be measured by using a conductivity meter. Conductivity measurements have been correlated with field emergence, especially in large-seeded crops like peas and corn (94).

Seedling Growth Seedling grow-out tests can be conducted under greenhouse or growth-chamber conditions, and vigor calculated based on seedling emergence and uniformity (Fig. 6–28d). An alternative to plug and flat germination includes evaluations like the slant-board test that uses similar conditions as the standard germination test for percentage germination. After a period of time at a controlled temperature (this varies between species), shoot and root length or seedling weight is determined (Fig. 6–29a). This permits a determination of strong versus weak seedlings in a seed lot. Measuring individual seedlings can be tedious, but advances in computer-aided image analysis offer an alternative to hand measurements (Fig. 6–29b) (71, 105). Ball Seeds Inc. (West Chicago, IL) has introduced the Ball Vigor Index that employs computer analysis of video images of seedlings in plug trays after a predetermined number of days. The index is suggestive of seedling greenhouse performance.



(a)



(b)

Figure 6–29

(a) A slant-board test for lettuce. Seedling must be grown in an upright orientation to get straight seedlings. Radicle length is then measured by hand. (b) Computer-aided measurements of digital images of petunia from Petri dish germination.

Trade Agreement) require clean seed be made available for international sale.

Specific procedures to standardize seed health tests are available (137). Three types of tests for seed health include:

1. **Visual evaluation** of a seed sample for characteristic structures like spores or sclerotia of pathogens, or the presence of insects.
2. **Incubation of seed** on moist germination paper or agar and inspection for disease growth.
3. **Biochemical tests**, such as ELISA tests, which detect the presence of specific disease organisms.

SEED TREATMENTS TO IMPROVE GERMINATION

Presowing seed treatments has become a common practice in the seed industry. Seed treatments may be applied by seed producers or on the farm. The objective of seed treatments is to either enhance the potential for germination and seedling emergence or to help mechanical seed sowing (75, 120, 132). Types of seed treatments include:

1. Seed protectants
2. Germination enhancement



3. Inoculation with microorganisms (nitrogen-fixing bacteria)
4. Coatings to help mechanical sowing

Facilities that treat seeds must consider the following aspects for quality seed treatment (56):

1. Seeds must be treated **uniformly**.
2. The material must continue to **adhere to the surface** of the seed during sowing.
3. The treatment should **not reduce seed quality**. Any physical damage due to high temperature or mechanical injury must be minimized and monitored by seed testing.
4. The treatment should be **safely applied** and allow for safe handling by the seed consumer.
5. Treatments to **help mechanical sowing** must produce a **uniform size** and **shape** for each seed.
6. All seeds treated with a pesticide must be **colored** to avoid accidental ingestion by humans or animals. Color can also enhance the appearance of the seed.

Modern seed treatments require specialized equipment and facilities (30, 56, 57). The equipment varies depending on the type of seed treatment. Historically, the first seed treatment incorporated pesticides in simple powders (74). These are still used today, especially for on-site farm application, because they require the least specialized equipment. However, powders and the dust from them present a problem for safe handling. Most commercial treatment of seeds is from **liquid slurries**. These are preferred because they treat seeds more uniformly, are safer to apply and handle, and are relatively cheap.

Recently, **polymer film coatings** have become a popular seed treatment because the pesticide can be incorporated into the polymer that is applied in a thin, uniform coat or film (57). The advantages of film coatings are the ability to incorporate chemical or biological materials into the coating for safe handling (this material does not rub off when handled), uniform coating size, and an attractive appearance. The cost has been prohibitive for general use with many large-volume agronomic crops, but film-coated seeds have become more widely available on high-value flower and vegetable seed.

Seed Protectants

Seed protectants can be grouped as

1. **Chemical treatments** against pathogens, insects, and animals.
2. **Heat treatment** against pathogens and insects.

3. **Inoculation** with **beneficial microbes** against harmful fungi.
4. **Safeners**, to reduce herbicide injury (19, 120).

Chemical Treatment A seed stores food reserves to provide energy and carbon for seedling growth, which makes seeds a primary food source for humankind. However, insects, pathogens, and animals also target seeds as a food source. Strategies to protect seeds probably date to man's earliest use of seeds as a food crop (74). Chemical treatments for seeds can be seen in the 1800s with the use of copper sulfate against a variety of cereal diseases (120). In the 1900s, mercury compounds were very effective against seed and seedling pathogens. These were banned in most parts of the world in the 1980s because of health risks. The 1940s and 1950s saw the introduction of the first broad-spectrum fungicides (like captan and thiram), starting the modern use of seed protectants for diseases.

The most common and important seed treatments are the chemical and physical treatments against seed-borne pathogens (20) and insects (79). It is important to understand that these treatments will not improve germination in seeds with a genetically low potential for germination or in mechanically injured seeds. These treatments are especially beneficial where germination is delayed due to poor environmental conditions such as excessive water in the field, or cool soils. Under these conditions, seed leakage stimulates fungal spore germination and growth. A chemical seed treatment can protect the seed until the seedling emerges.

Seed treatment may be designed to protect seed from soil-borne pathogens, disinfest the seed from pathogens on the seed surface, or eliminate pathogens inside the seed (20). Chemical seed protectants can be applied as **powders**, **liquids**, **slurries**, or incorporated into a pellet or **film coating** (57, 75).

Biocontrol Although chemical treatments dominate industry seed treatments, the novel use of treating seeds with **beneficial microbes** presents an interesting alternative to chemical treatments (100, 112, 118). Various

seed protectants

Seed treatments used most often for field-seeded crops that are prone to insect and disease attack. Early season plantings that are slower to emerge because of cool soils benefit from seed protectants.

geneficial microbes

An alternative to chemicals for seed protection against soil-borne diseases. These microbes compete with pathogenic microbes to help seedlings emerge before they are attacked.



biocontrol agents provide protection to seeds by producing antibiotic substances; decreasing competition for space and nutrients; and reducing parasitism (63, 100). Common biocontrol agents include bacterial strains like *Eterobacter*, *Pseudomonas*, *Serratia*, and fungal strains like *Gliocladium* and *Trichoderma*. Several studies show disease prevention with biologicals to be as effective as chemical treatment with fungicides (27, 129). A second approach is to treat seeds with materials extracted from fungi or bacteria that activate the plant's natural defense system (145).

Heat Treatment (Thermotherapy) High temperature to control seed-borne diseases has been in use since 1907 (74). Dry seeds are immersed in hot water (49 to 57°C; 120 to 135°F) for 15 to 30 minutes, depending on the species (10, 11). After treatment, the seeds are cooled and spread out in a thin layer to dry. To prevent injury to the seeds, temperature and timing must be regulated precisely; a seed protectant should subsequently be used, and old, weak seeds should not be treated. Hot water is effective for specific seed-borne diseases of vegetables and cereals, such as *Alternaria* blight in broccoli and onion, and loose smut of wheat and barley.

Microwave and UV radiation also can be used to disinfest seeds (121). Aerated steam (see Chapter 3) is an alternate method that is less expensive, easier to manage, and less likely to injure seeds than hot water. Seeds are treated in special machines in which steam and air are mixed and drawn through the seed mass to rapidly (in about two minutes) raise the temperature of the seeds to the desired temperature. The treatment temperature and time vary with the organism to be controlled and the kind of seed. Usually the treatment is 30 minutes, but it may be as little as 10 or 15 minutes. Temperatures range from 46 to 57°C (105 to 143°F). At the end of treatment, temperatures must be lowered rapidly to 32°C (88°F) by evaporative cooling until dry. Holding seeds in moisture-saturated air at room temperature for 1 to 3 days prior to the steam-air treatment will improve effectiveness.

Hot water is also used to kill insects in seeds. For example, oak (*Quercus*) seed is soaked in water at 49°C (120°F) for 30 minutes to eliminate weevils commonly found in acorns (149). As with heat treatments to eliminate disease, precise temperature and timing must be maintained or seeds will be damaged.

Seed Coating

Seed coating uses the same technology and equipment used by the pharmaceutical industry to make medical pills (82, 131). Seed coatings include **pelleted** and **film-coated** seeds (26).

Pelleted Seeds The objective of coating seeds as a pellet is to provide a **round, uniform shape** and **size** to small or unevenly shaped seeds in order to aid precision mechanical sowing (Fig. 6–30). Pelletized seeds are tumbled in a pan while inert powders (like clay or diatomaceous earth) and

binders form around seeds to provide a uniform, round shape (Fig. 6–31). Recent advances in coating materials and processing using rotary coaters has allowed seed producers to produce thinner pellets (Fig. 6–30b). These are usually termed **encrusted** seeds for very thin coatings (1 to 5 times the seed size) or mini-pellets (10 to 25 times the seed size). Compare this with a traditional pellet that may be 50 to 100 times the seed size (Fig. 6–30c and d). Encrusted seeds are similar to film-coated seeds but are less expensive to produce. Pellets can be distinguished by either “splitting” or “melting” when the coating is wetted, with many growers preferring the split-type pellets (Fig. 6–30e). Many ornamental flower seeds are commonly pelletized for precision sowing one seed per cell in a plug flat (see Chapter 7). An increasing number of direct-seeded vegetable crops are also being pelletized. It is common for lettuce seed sown in Florida and California to be pelletized to provide uniform spacing and sowing depth that reduces the need to hand-thin the crop.

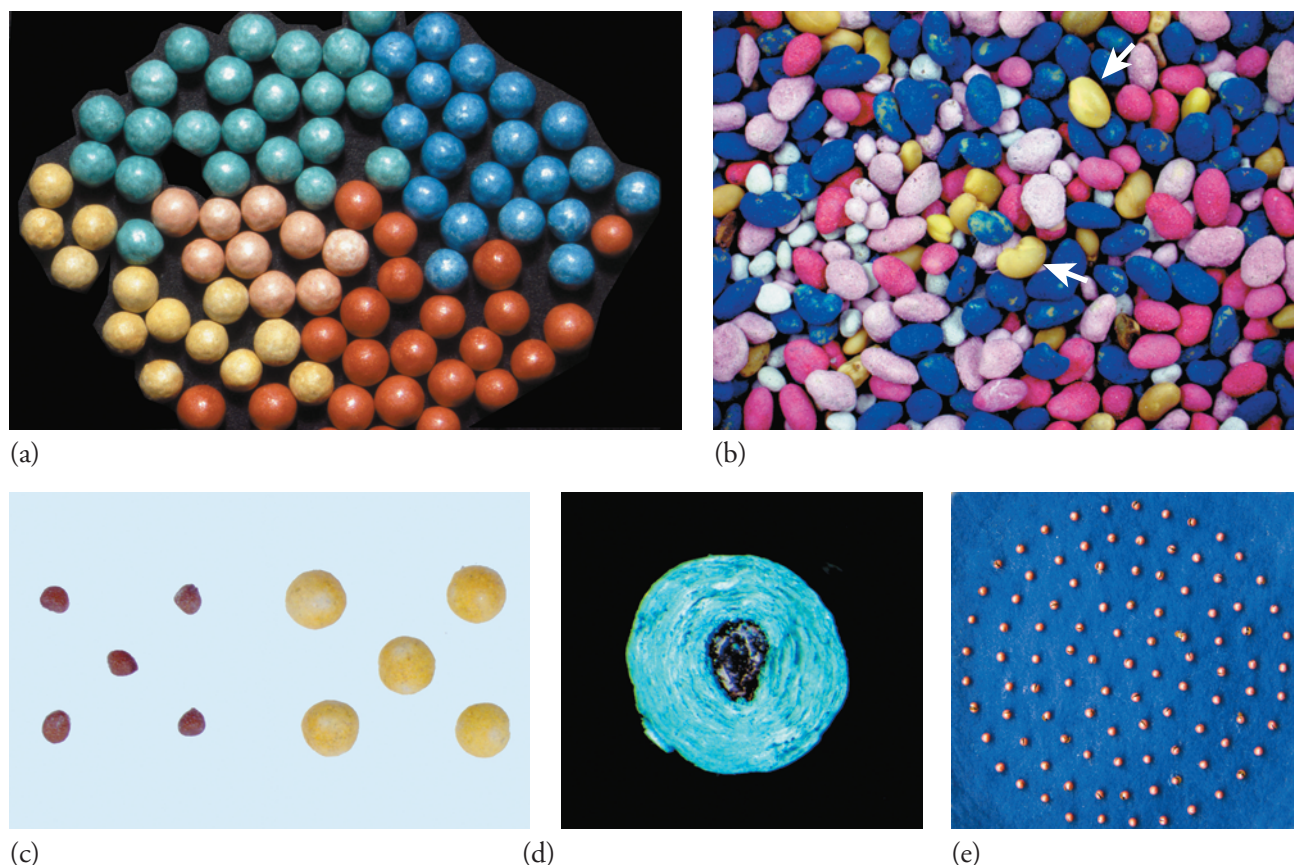
Polymer Film-Coated Seeds Film coating (Fig. 6–32, page 188) uses a thin polymer film to cover the seed (82, 114). Film coating only adds 1 to 5 percent to the weight of a seed compared with more than 1,000 percent for pelletized seed, but this can still aid in precision sowing by improving flowability. Fungicides and beneficial microbes can be added to both pellets and film coatings (see seed treatments, p. 184) and is the major benefit to film coating (57). Novel films are being employed that allow seeds to imbibe only when the soil temperature has warmed to prevent imbibitional chilling injury in sensitive plants (103).

Germination Enhancement

Commercial practices that provide germination enhancement are **seed sizing**, **priming**, and **pregermination** (48, 57).

Seed Sizing Seed lots sold as “elite” seeds have been sized to provide larger seed. In addition, seed sizing eliminates lightweight and cracked seeds (Fig. 6–33,

pelleted seeds Seeds that have a round, uniform shape that make it easier for machine sowing. Pelleted seeds are most commonly used in greenhouse bedding plant production and precision-sown vegetable crops.

**Figure 6-30**

Seed Pellets (a) Pelleted seeds showing the uniformly round shape to help in mechanical sowing. Colors may indicate seed differences (primed vs. untreated) or just be cosmetic. (b) A collection of encrusted pasture legume seeds. Notice how the seed shape is still evident with the lighter pelleted coating; the arrows indicate non-encrusted seeds. (c and d) Seed pelleting adds considerable size to a seed as well as a uniform, round shape. (c) On the left are raw seeds versus pelleted seeds on the right. (d) A cross-section of a pelleted seed showing how the coating (light blue) adds significant volume to the seed. (e) Pellets showing the split-coat habit as it hydrates. Splitting allows easy penetration by the radicle of the germinating seed.

**Figure 6-31**

Pan type seed coater for pelletizing seeds. Seeds tumble in this seed coating machine while layers of a bulking material and binder build the pellet around the seed.

page 188). This can provide seeds with a higher potential for germination viability and vigor. Elite seeds also may

seed priming A controlled hydration seed treatment that induces faster, more uniform germination. This effect is most noticeable when seeds are sown in less-than-favorable environments. Primed seeds are most often used in greenhouse bedding plant production to shorten the time to produce seedling plugs, and in crops like pansy and lettuce to avoid reduced germination due to high temperature.

be the seeds selected by seed companies to be further enhanced by seed priming.

Seed Priming **Seed priming** is a controlled seed-hydration treatment that can reduce the time it takes for seedlings to emerge. It uses basic principles of water potential to hold seeds in an imbibed condition, but prevent germination

**Figure 6-32**

Film coating is used to improve flowability of seeds during planting and as a carrier for pesticides. Several examples of film coating on corn seed. Seeds on the left are untreated.

(radicle emergence) (24, 97). After being hydrated for an extended time, seeds are dried back to near the original dry weight. These seeds can be handled as normal raw seeds or pelleted prior to sowing (82). Growth substances (28) or biologicals (termed *biopriming*; 20, 27) also can be included in the priming solution for added seed enhancement.

Primed seeds will usually show higher seed vigor compared with raw seeds (97). The physiological basis for seed priming is discussed in Chapter 7. Priming can provide faster, more uniform seedling emergence for field and greenhouse crops, especially when environmental conditions for germination are not ideal. The grower must weigh the additional cost of primed seed with this potential for improved seedling emergence. It is common to prime crops like lettuce (106) and pansy (29) to overcome problems of reduced germination due to conditions of high temperature (thermodormancy, see Chapter 7).

Pregermination The goal of each grower is to establish a “stand” (seedling emergence) of 100 percent (54), which means a plant at each appropriate field spacing or greenhouse plug cell (see Chapter 8). This can be accomplished by using transplants or sowing more seeds than are required and thinning seedlings to the appropriate spacing. An additional treatment to improve stand establishment is pregermination of seeds. In concept, pregermination can take place under optimum conditions and any seeds showing radicle emergence are sown, providing near 100 percent stand. Two types of pregermination sowing techniques have been used:

1. **Fluid drilling** to sow germinated seeds in a gel to protect emerged radicles.
2. **Pregerminated** seeds that use a technique to dry seeds after the radicle emerges prior to sowing.

Fluid Drilling. **Fluid drilling** (55, 107) is a system involving the treatment and pregermination of seeds followed by their sowing suspended in a gel. Seeds are pregerminated under conditions of aeration, light, and optimum temperatures for the species (Fig. 6-22). Among the procedures that can be used are (a) germinating seeds in trays on absorbent blotters covered with paper, or (b) placing seeds in water in glass jars or plastic columns through which air

fluid drilling A technique to sow pregerminated seeds where the radicle has emerged and is vulnerable to damage. Germinated seeds are mixed in a gel for sowing. Fluid drilling has not been used extensively because of the expense and difficulty in timing. It has its greatest utility in high-value vegetable crops sown in cool soils for early harvest.



(a)



(b)

Figure 6-33

(a) “Elite” or enhanced seeds have additional seed conditioning to remove any broken seeds and have been sized to give larger, more uniform seeds. (b) Notice the broken and small seeds (arrow) in the seed lot on the right.



is continuously bubbled and fresh water continuously supplied. Growth regulators, fungicides, and other chemicals (51) can potentially be incorporated into the system. Chilling (10°C, 50°F) of thermodormant celery seeds for 14 days has produced short, uniform radicle emergence without injury (47). Pregerminated seeds of various vegetables have been stored for 7 to 15 days at temperatures of 1 to 5°C (34 to 41°F) in air or aerated water. Separating out germinated seeds by density separation has improved the uniformity and increased overall stand (130).

Various kinds of gels are commercially available. Among the materials used are sodium alginate, hydrolyzed starch-polyacrylonitrile, guar gum, synthetic clay, and others. Special machines are needed to deposit the seeds and gel into the seed bed.

Pregerminated Seeds. **Pregerminated seeds** were introduced commercially in 1995 for bedding plant

pregerminated seeds

A technique for bedding plants that uses a special process to synchronize radicle emergence and then slowly dry seeds prior to sowing. Under the right conditions, this treatment ensures near 100 percent germination.

species (impatiens), but L. H. Bailey introduced the concept as early as 1897. A quote from Bailey's *The Nursery Book* (8) demonstrates that "new" is truly a relative term as he describes "regermination." "It

is a common state-

ment that seeds can never revive if allowed to become thoroughly dry after they have begun to sprout. This is an error. Wheat, oats, buckwheat, maize, pea, onion, radish, and other seeds have been experimented upon in this direction, and they are found to regerminate readily, even if allowed to become thoroughly dry and brittle after sprouting is well progressed. They will even regerminate several times."

Pregermination involves germination of seeds under controlled conditions to synchronize germination in order to induce the radicle to emerge about one-sixteenth of an inch. Germinated seeds are separated from nongerminated seeds, and then seeds are dried slowly to near their original dry weight (26). The advantages of using pregerminated seeds include production of 95 percent or better usable seedlings; fast, uniform germination; and because the seeds are dry, mechanical seeders can be used to sow them. The disadvantages of using pregerminated seeds are increased cost (up to 25 percent), seeds have a shorter shelf life

(around 35 days at 5°C or 40°F), and growers must have optimized seedling growing conditions to take advantage of the benefits of pregermination.

SEED STORAGE

Seeds are usually stored for varying lengths of time after harvest. **Viability** at the end of storage depends on (a) the initial viability at harvest, as determined by factors of production and methods of handling; and (b) the rate at which deterioration takes place. This rate of physiological change, or aging (96, 111), varies with the kind of seed and the environmental conditions of storage, primarily temperature, and humidity.

viability A measure of whether the seed is alive and can germinate.

Seed Longevity

Plant species can be separated as **recalcitrant** or **orthodox** seeds based on their genetic potential to tolerate storage.

Recalcitrant or Short-Lived

Seeds **Recalcitrant** seeds do not tolerate significant drying after seed development. Most recalcitrant seeds cannot tolerate seed moistures below 25 percent, and some species are also sensitive to chilling temperatures. This group is represented by species whose seeds normally retain viability for as little as a few days, months, or at most a year following harvest (see Chapter 5). However, with proper handling and storage, seed longevity may be maintained for significant periods. A list of species with short-lived seeds has been compiled by King and Roberts (83). The group includes:

orthodox seeds

Seeds that tolerate drying after seed development; can usually be stored for years in this dry state. The majority of crop plants have orthodox seeds.

recalcitrant seeds

Seeds that do not tolerate drying after seed development. They offer special challenges in storage because they are short-lived.

1. Certain spring-ripening, temperate-zone trees such as poplar (*Populus*), maple (*Acer*) species, willow (*Salix*), and elm (*Ulmus*). Their seeds drop to the ground and normally germinate immediately.



2. Many tropical plants grown under conditions of high temperature and humidity; these include such plants as sugarcane, rubber, jackfruit, macadamia, avocado, loquat, citrus, many palms, litchi, mango, tea, choyote, cocoa, coffee, tung, and kola.
3. Many aquatic plants of the temperate zones, such as wild rice (*Zizania*), pondweeds, arrowheads, and rushes.
4. Many tree nut and similar species with large fleshy cotyledons, such as hickories and pecan (*Carya*), birch (*Betula*), hornbeam (*Carpinus*), hazel and filbert (*Corylus*), chestnut (*Castanea*), beech (*Fagus*), oak (*Quercus*), walnut (*Juglans*), and buckeye (*Aesculus*).

Orthodox Seeds

The majority of important crop plants are species with **orthodox seeds**. Orthodox seeds tolerate drying after seed development and can be stored in a dry state (usually 4 percent to 10 percent moisture) for extended periods of time. Species with orthodox seed behavior vary in the length of time they tolerate storage.

Medium-Lived Seeds. Medium-lived seeds remain viable for periods of 2 or 3 up to perhaps 15 years, providing that seeds are stored at low humidity and, preferably, at low temperatures. Seeds of most conifers, fruit trees, and commercially grown vegetables, flowers, and grains fall into this group. Crop species can be grouped according to the ability of seeds to survive under favorable ambient storage conditions (Table 6–2). The Relative Storability Index (78) indicates the storage time where 50 percent or more of seeds can be expected to germinate. Seed longevity will be *considerably longer* under controlled low temperature and humidity storage.

Long-Lived Seeds. Many of the longest-lived seeds have hard seed coats that are impermeable to water. Plant families that produce seeds with hard seed coats include the legume, geranium, and morning glory families. If the hard seed coat remains undamaged, such seeds can remain viable for at least 15 to 20 years. The maximum life can be as long as 75 to 100 years and perhaps more. Records exist of seeds being kept in museum cupboards for 150 to 200 years while still

Table 6–2
RELATIVE STORABILITY INDEX^a

Crop	Category 1 (1 to 2 yr)	Category 2 (3 to 5 yr)	Category 3 (>5 yr)
Agronomic	Bermuda grass	Barley	Alfalfa
	Cotton	KY Bluegrass	Clover
	Field corn	Fescue	Sugar beet
	Millet	Oats	Vetch
	Peanut	Rape seed	
	Soybean	Rice	
	Sunflower	Wheat	
Vegetable	Green bean	Broccoli, cabbage, cauliflower	Beet
	Lettuce	Cucumber	Tomato
	Onion	Melon	
	Pepper	Pea	
		Spinach	
		Sweet corn	
Flower	Begonia	Alyssum	Hollyhock
	Coreopsis	Carnation	Morning glory
	Pansy	Coleus	Salpiglossis
	Primrose	Cyclamen	Shasta daisy
	Statice	Marigold	Stocks
	Vinca	Petunia	Zinnia

^a The relative storability index is the expected 50 percent germination in a seed lot stored under favorable ambient conditions. Storage life would be longer under controlled low temperature conditions.

Source: Adapted from Justice and Bass, 1979.



retaining viability (115). There are a number of claims of seeds from ancient tombs germinating after thousands of years. However, these lack definitive scientific support (115). Indian lotus (*Nelumbo nucifera*) seeds that had been buried in a Manchurian peat bog were originally estimated to be more than 1,000 years old and germinated perfectly when the impermeable seed coats were cracked (21). However, recent carbon-14 dating of these and other lotus seeds estimate the age of these seeds to be only 100 to 430 years old (115)!

A systematic study was initiated by Beal in 1879 at Michigan State University to study long-term survival of buried seed. This study is still ongoing, and in 1981 (84) and 2001 (136), three species continued to show germination after 100 and 120 years, respectively. These species were *Malva rotundifolia*, *Verbascum blattaria*, and *Verbascum thapsus*. Some weed seeds retain viability for many years (50 to 70 years or more) while buried in the soil, even though they have imbibed moisture (113). Longevity seems related to dormancy induced in the seeds by environmental conditions deep in the soil.

Storage Factors Affecting Seed Germination

As seeds **deteriorate**, they:

1. first **lose vigor**,
2. then the **capacity for normal germination**,
3. and finally **viability**.

Storage conditions that reduce seed deterioration are those that slow respiration and other metabolic processes without injuring the embryo. The most important conditions are low moisture content of the seed, low storage temperature, and modification of the storage atmosphere. Of these, the moisture-temperature relationships have the most practical significance. Harrington (64) introduced a “rule of thumb” that indicated that seeds lose half their storage life for every 1 percent increase in seed moisture between 5 percent and 14 percent. Also, seeds lose half their storage life for every 5°C increase in storage temperature between 0 and 50°C. This is, of course, a generalized theory that varies between species. More accurate mathematical models have been developed to predict seed longevity at various temperature and moisture contents (43).

The most important factors impacting extended seed longevity in storage are seed moisture content and storage temperature.

Moisture Content Control of seed moisture content is probably the most important factor in seed longevity and storage. Most crop species have orthodox seeds

where dehydration is their natural state at maturity. These seeds are best stored at a non-fluctuating low moisture content (43).

Seeds of orthodox species are desiccation-tolerant and, for most, 4 percent to 6 percent moisture content is favorable for prolonged storage (33), although a somewhat higher moisture level is allowable if the temperature is reduced (138). For example, for tomato seed stored at 4.5 to 10°C (40 to 50°F), the percent moisture content should be no more than 13 percent; if 21°C (70°F), 11 percent; and if 26.5°C (80°F), 9 percent.

Various storage problems arise with increasing seed moisture (64). At 8 percent or 9 percent or more, insects are active and reproduce; above 12 percent to 14 percent, fungi are active; above 18 percent to 20 percent, heating may occur due to seed respiration; and above 40 percent to 60 percent, germination occurs.

If the moisture content of the seed is too low (1 percent to 2 percent), loss in viability and reduced germination rate can occur in some kinds of seeds (17). For seeds stored at these low moisture levels, it would be best to rehydrate with saturated water vapor to avoid injury to seed (104). Moisture in seeds is in equilibrium with the relative humidity of the air in storage containers, and increases if the relative humidity increases and decreases if it is reduced (64). Thus, moisture percentage varies with the kind of storage reserves within the seed (13, 14). Longevity of seed is best if stored at 20 percent to 25 percent relative humidity (115).

Since fluctuations in seed moisture during storage reduce seed longevity (15), the ability to store seeds exposed to the open atmosphere varies greatly in different climatic areas. Dry climates are conducive to increased longevity; areas with high relative humidity result in shorter seed life. Seed viability is particularly difficult to maintain in open storage in tropical areas.

Storage in hermetically sealed, moisture-resistant containers is advantageous for long storage, but seed moisture content must be low at the time of sealing (16). Seed moisture content of 10 percent to 12 percent (in contrast to 4 percent to 6 percent) in a sealed container is worse than storage in an unsealed container (33, 115).

Recalcitrant seeds owe their short life primarily to their sensitivity to low moisture content. For instance, in silver maple (*Acer saccharinum*), seed moisture content was 58 percent in the spring when fruits were released from the tree. Viability was lost when moisture content dropped below 30 percent to 34 percent (76). Citrus seeds can withstand only slight drying (15) without loss of viability. The same is true for seeds of some water plants, such as wild rice, which can be



stored directly in water at low temperature (102). The large fleshy seeds of oaks (*Quercus*), hickories (*Carya*), and walnut (*Juglans*) lose viability if allowed to dry after ripening (119).

Viability of recalcitrant seeds of the temperate zone can be preserved for a period of time if kept in a moist environment and the temperature is lowered (21). Under these conditions many kinds of seeds can be kept for a year or more. Seeds of some tropical species (e.g., cacao, coffee), however, show chilling injury below 10°C (50°F).

Temperature Reduced temperature invariably lengthens the storage life of seeds and, in general, can offset the adverse effect of a high moisture content. Subfreezing temperatures, at least down to -18°C (0°F), will increase storage life of most kinds of seeds, but moisture content should not be high enough to allow the free water in the seeds to freeze and cause injury (115). Refrigerated storage should be combined with dehumidification or with sealing dried seeds in moisture-proof containers.

Cryopreservation. Survival of seeds exposed to ultralow temperatures (cryopreservation) has been known since 1879 (25). There is renewed interest in storage of seeds by cryopreservation because it is

cryopreservation The storage of seeds or vegetative organs at an ultralow temperature. This is usually in liquid nitrogen at -196°C.

potentially a cost-effective way to preserve germplasm for long periods of time with minimal loss of genetic information due to chromosomal mutations that accompany seed deterioration (124). Seeds are cryopreserved by immersion and storage in liquid nitrogen at -196°C (Fig. 6-34). Seed moisture must be low for survival, and gradual cooling and warming rates limit damage to the seed like cracks in the seed coat (115).

Cryopreservation of seeds has not replaced standard long-term storage at -18°C because long-term effects on seed survival have yet to be determined (142). However, numerous species have been stored for short periods of time in liquid nitrogen with promising results (123, 125). Research is continuing, especially at the National Seed Storage Lab (see Getting More In Depth on the Subject box on conserving genetic resources) to make cryopreservation an important tool for seed preservation. Cryopreservation technology is also being applied to other tissue like pollen and dormant buds for possible preservation of germplasm (9, 81).

Types of Seed Storage

Although optimal seed storage conditions are cold temperature and low relative humidity, it is not always possible to maintain these conditions for commercial seed lots because of economic reasons. Typical conditions for commercial storage listed from least to most expensive include: (Fig. 6-35)



(a)



(b)



(c)

Figure 6-34

Germplasm storage. (a) Movable storage cabinets for seed storage. (b and c) Seed storage in liquid-nitrogen-filled dewars.

**Figure 6-35**

Various seed storage methods.

(a) Small, high value seeds in plastic containers. (b) Vegetable seeds stored in sealed cans. (c) Large-seeded vegetables in bulk storage in waxed boxes. (d) Conditioned storage for crop seeds. (e) Refrigerator storage for flower seeds.

1. **Open storage** without humidity or temperature control
2. Storage in **sealed containers** with or without temperature control
3. **Conditioned storage** with humidity and temperature control

Open Storage without Humidity or Temperature Control Many kinds of orthodox seeds need to be stored only from harvest until the next planting season. Under these conditions, seed longevity depends on the relative humidity and temperature of the storage atmosphere, the kind of seed, and its condition at the beginning

BOX 6.5 GETTING MORE IN DEPTH ON THE SUBJECT CONSERVING GENETIC RESOURCES



Crop cultivars produced for food, fiber, and ornamentals represent only a small proportion of the worldwide gene pool that could have economic benefit in the future. This is a genetic resource that is most easily and economically preserved by storing seed from diverse populations of crop plants. Facilities that provide long-term storage of seeds or other plant parts are called "gene banks" (108).

The International Board for Plant Genetic Resources (72) was established in 1974 to promote an international network of gene banks to conserve genetic resources mainly by storing seeds for the long term. (62). This organization provides handbooks and describes the criteria for facilities that store seed germplasm (41, 42, 62). Facilities are described for either long-term or medium-term storage. Long-term storage facilities provide an environment and testing regime to maintain seed viability and plant recovery for from 10 to more than 20 years. Medium-term storage facilities are designed to preserve seeds for 5 to 10 years before having to regrow the crop to produce fresh seed. In 1984, more than 100 storage

facilities (55 with long-term storage) had been established worldwide (62).

The major facility in the United States for preserving germplasm resources is the National Seed Storage Laboratory, established in 1958 on the Colorado State University campus (115, 141). Seeds are actively acquired from public agencies, seed companies, and individuals engaged in plant breeding or seed research. Descriptive material is recorded for each new accession on the Germplasm Resources Information Network. Seed samples are tested for viability, dried to approximately 6 percent moisture, and stored at -18°C (0°F) in moisture-proof bags. Seed lot sizes vary for storage from between 3,000 to 4,000 seeds for cross-pollinated species and 1,500 to 3,000 seeds for pure lines. Seed lots are tested every 5 or 10 years for germination. Seeds can be made available to breeders and researchers on request. This facility also conducts seed storage research and is one of the leading centers for research on cryopreservation of seeds. Information on germplasm can be obtained online at <http://www.ars-grin.gov>.



of storage. Basic features (78) of the storage structures include (a) protection from water, (b) avoidance of mixture with other seeds or exposure to herbicides, and (c) protection from rodents, insects, fungi, and fire. Retention of viability varies with the climatic factors of the area in which storage occurs. Poorest conditions are found in warm, humid climates; best storage conditions occur in dry, cold regions. Fumigation or insecticidal treatments may be necessary to control insect infestations.

Open storage can be used for many kinds of commercial seeds for at least a year (i.e., to hold seeds from one season to the next). Seeds of many species, including most agricultural, vegetable, and flower seeds, will retain viability for longer periods up to 4 to 5 years (17, 78), except under the most adverse conditions.

Sealed Containers Packaging dry seeds in hermetically sealed, moisture-proof containers is an important method of handling and/or merchandising seeds. Containers made of different materials vary in durability and strength, cost, protective capacity against rodents and insects, and ability to retain or transmit moisture. Those completely resistant to moisture transmission include tin or aluminum cans (if properly sealed), hermetically sealed glass jars, and aluminum pouches. Those almost as good (80 percent to 90 percent effective) are polyethylene (3 mil or thicker) and various types of aluminum-laminated paper bags. Somewhat less desirable, in regard to moisture transmission, are asphalt and polyethylene-laminated paper bags and friction-top tin cans. Paper and cloth bags give no protection against moisture change (46). Small quantities of seeds can be stored satisfactorily in small moisture-proof containers like mason jars or plastic food containers.

Seed may be protected against moisture uptake by mixing with a desiccant (32, 78). A useful desiccant is silica gel treated with cobalt chloride. Silica gel (one part to ten parts seed, by weight) can absorb water up to 40 percent of its weight. Cobalt chloride turns from blue to pink at 45 percent RH and can act as a useful indicator of excess moisture. Seeds should not be stored in contact with the desiccant. Seeds in sealed containers are more sensitive to excess moisture than when subjected to fluctuating moisture content in open storage. Seed moisture content of 5 percent to 8 percent or less is desirable, depending on the species.

Conditioned Storage Conditioned storage includes use of dehumidified and/or refrigerated facilities to reduce temperature and relative humidity (115). Such facilities are expensive but are justified where particularly valuable commercial seeds are stored. It is also justified for research, breeding stocks, and germplasm.

Also in some climatic areas, such as in the highly humid tropics, orthodox seeds cannot be maintained from one harvest season to the next planting season.

Cold storage of tree and shrub seed used in nursery production is generally advisable if the seeds are to be held for longer than 1 year (68, 119). Seed storage is useful in forestry because of the uncertainty of good seed-crop years. Seeds of many species are best stored under cold, dry conditions (149). Ambient relative humidity in conditioned storage should not be higher than 65 percent to 75 percent RH (for fungus control) and no lower than 20 percent to 25 percent.

It is important to control humidity in refrigerated storage since the relative humidity increases with a decrease in temperature and moisture will condense on the seed. At 15°C (59°F), this equilibrium moisture may be too high for proper seed storage. Although the seed moisture content may not be harmful at those low temperatures, rapid deterioration will occur when the seeds are removed from storage and returned to ambient uncontrolled temperatures. Consequently, refrigeration should be combined with dehumidification or sealing in moisture-proof containers (64).

Low humidity in storage can be obtained by judicious ventilation, moisture proofing, and dehumidification as well as by the use of sealed moisture containers, or the use of desiccants, as described previously. Dehumidifiers utilize desiccants (silica gel) or saturated salt solutions. The most effective storage is to dry seeds to 3 percent to 8 percent moisture, place in sealed containers, and store at temperatures of 1 to 5°C (41°F). Below-freezing temperatures can be even more effective if the value of the seed justifies the cost.

Moist, Cool Storage for Recalcitrant Seeds. Many recalcitrant seeds that cannot be dried can be mixed with a moisture-retaining medium, placed in a polyethylene bag or other container, and refrigerated at 0 to 10°C (32 to 50°F). The relative humidity in storage should be 80 percent to 90 percent. Examples of species whose seeds require this storage treatment are silver maple (*Acer saccharinum*), buckeye (*Aesculus* spp.), American hornbeam (*Carpinus caroliniana*), hickory (*Carya* spp.), chestnut (*Castanea* spp.), filbert (*Corylus* spp.), citrus (*Citrus* spp.), loquat (*Eriobotrya japonica*), beech (*Fagus* spp.), walnut (*Juglans* spp.), litchi, tupelo (*Nyssa silvatica*), avocado (*Persea* spp.), pawpaw (*Asimina triloba*), and oak (*Quercus* spp.). The procedure is similar to moist-chilling (stratification). Acorns and large nuts may be dipped in paraffin or sprayed with latex paint before storage to preserve their moisture content (69).



DISCUSSION ITEMS

By far, more plants are propagated from seed for the production of food, fiber, and for ornamental use than any other propagation method. There are more recent advancements in techniques related to seed germination than any other area of plant propagation. It has become standard to purchase seeds treated with a pre-sowing treatment for vegetable and flower production. As examples, most pansy seed are primed to avoid thermodormancy for summer sowing. Lettuce seed is commonly pelleted to facilitate mechanical sowing, as are many flower seeds. Newer techniques (like pregermination) also must be evaluated by growers and may become important in the future. Seed quality and handling makes a large contribution to the production practices discussed in Chapter 8.

1. Contrast seed viability vs. vigor. How do these characteristics of seeds affect different horticulture crop production?
2. Standard germination is the number of normal seedlings produced in a seed lot. How does this compare to radicle emergence as a measure of viability?
3. Discuss disease protection of seeds by chemical vs. biological materials such as using the fungus *Trichoderma*.
4. What are the advantages of pelleted and film-coated seed?
5. Compare seed storage of orthodox vs. recalcitrant seeds.
6. Discuss strategies to conserve genetic resources.

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