

## Chapter 16 Tree Seed Processing



**Lars H. Schmidt** and **Kirsten A. Thomsen**  
Danida Forest Seed Centre, Krogerupvej 21,  
DK-3050 Humlebaek, Denmark



**Summary**

The purpose of seed processing is to obtain clean, pure seeds of high physiological quality, which can be stored and easily handled during pretreatment, transport and sowing.

The first step is pre-cleaning (in the field after collection or at the processing plant), which is done to reduce bulk before transport and to remove material that may contaminate the seeds. If the fruits or seeds are stored temporarily in the field, it is very important to avoid extreme conditions in which the seeds may lose viability. This also applies to the transport from the field to the processing plant. Seeds of some species cannot be extracted from the fruit. Some other species need pre-curing or post-harvest ripening to facilitate seed extraction or to obtain maximal seed quality. Seed extraction methods depend on the species and include a number of different techniques like drying and tumbling, dewinging, threshing and soaking followed by maceration and washing. After extraction, the seeds are cleaned to reduce bulk and to remove contaminating material and seeds of other species. Finally, the seeds are dried to the optimal moisture content for storage.

**Box 16.1 Seed processing steps**

Processing can be grouped into the following 6 procedures:

1. **Pre-cleaning**, for fruit or seed lots containing debris, leaves, twigs, empty fruit parts etc.
2. **Pre-curing**, for fruits that must be post-harvest ripened, or where rapid desiccation hampers extraction.
3. **Extraction**, for species where the fruits are collected but only the seeds are stored and sown.
4. **Dewinging**, for fruits and seeds with wings. Also includes removal of dry appendices like spines and hairs.
5. **Cleaning**, to remove impurities like fruit parts, leaves, twigs, empty seeds, foreign seeds and chaff.
6. **Drying**, to reduce seed moisture content to that considered optimal for storage of the particular species.

## Pre-cleaning and Temporary Storage

Pre-cleaning is done to maintain viability and reduce bulk. Newly collected fruits and seeds are particularly susceptible to damage because they often have a high seed moisture content.

A moisture content of 10–20% at the time of collection is normal for many orthodox seeds. Some orthodox seeds, immature orthodox seeds and mature recalcitrant seeds have considerably higher moisture contents, often 30–50%. High seed moisture level implies a risk of deterioration as it creates an ideal environment for fungi and bacteria and it accelerates the ageing process in the seeds. Moist fruits and seeds respire, which creates heat and consumes oxygen. If the oxygen is depleted because of inadequate aeration, fermentation replaces respiration. Both respiration and fermentation create heat, and since high temperature in connection with high moisture content tends to accentuate respiration or fermentation, the process can be self-accelerating, resulting in destruction of the whole fruit lot.

How fast the seed deteriorates depends on species, physiological quality of the seed at collection, contamination of the seed lot with dirt, leaves, rotten fruits, twigs, etc. and the external environment e.g., temperature and relative humidity.

Generally, the sooner the seeds are processed the better. If the seeds can be transported to the processing plant within a day after collection, special seed handling procedures in the field can normally be omitted. However, when collection expeditions are of longer duration or it is too impractical to transport the whole fruits, some pre-cleaning or extraction in the field can be necessary.

### 1. Seed Extraction in the Field

Fruits are normally bulky compared to seeds, so extraction will almost always reduce bulk and weight considerably, saving resources during transport.

Extraction of seeds from dry dehiscent fruits like those of many *Fabaceae* (*Leguminosae*) and *Myrtaceae* and gymnosperm cones is often easily and quickly done in the field provided weather conditions are dry. The fruits are spread out on a tarpaulin and as the mature fruits dry, they will normally split open and release their seeds; sometimes a little additional mechanical impact like raking or shaking is needed. Once the seeds have been released, empty fruits and debris can be removed manually or by raking.

Seeds from pulpy fruits may have to be extracted to avoid damage from fermentation of the pulp. If temperatures are high and the fruits are bulked in large containers, fermentation can start very fast.

In some cases, seed extraction should be avoided e.g., when the fruits should be after-ripened, if the seeds are very fragile or if the seeds are recalcitrant and in danger of desiccating during transport.

A summary of how to maintain viability and extract seeds of different kinds of fruits is given in Table 16.1.

<b>Storage physiology</b>	<b>Fruit type</b>	<b>Maintenance of viability</b>	<b>Extraction (bulk reduction)</b>
<b>Orthodox</b>	Dry dehiscent	(Sun) drying	Drying - shaking - sifting or manual removal of fruit parts
	Dry indehiscent	(Sun) drying	Flailing, pounding or threshing - sifting or manual removal of fruit parts
	Serotinous	(Sun) drying	Scorching - shaking - sifting
	Fleshy	Thin pulped: (Sun) drying Others: Depulping by pounding or washing	Depulping
	Immature	Moist storage	Not applicable
<b>Recalcitrant</b>	Dry	Moist storage	Drying dehiscence, sifting or manual removal of fruit parts
	Fleshy	Depulping – moist storage	Depulping

## 2. Conditions during Temporary Storage

Besides removal of decomposing fruit parts and other material that may contaminate the seed lot, three factors are of utmost importance in maintaining seed viability: moisture content, temperature and ventilation.

Orthodox seeds, should be kept as dry as possible. However, desiccation sensitive (recalcitrant) seeds must not dry below a certain level, so they should generally be kept moist and well aerated, although it can be difficult to achieve both in combination.

Not only high temperatures are detrimental for the seeds. Many tropical species have seeds that are sensitive to low temperatures (below 15°C), so fruits and seeds should only be stored temporarily in a fridge if they are known to tolerate low temperatures.

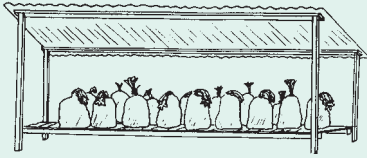
Some practical guidelines for temporary storage are given in Figure 16.1.

### Pre-curing and Post-harvest Ripening

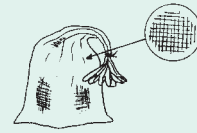
Pre-curing denotes the procedure during which fruits are kept moist for a prolonged period before extraction. Pre-curing has two rationales: 1) to promote ripening of immature fruits, and 2) to ease extraction of seeds where rapid desiccation may cause extraction problems, in extreme cases hardening of the fruit coat.

Only fruits that are not mature should be ripened. If the seed lot varies in maturity, as can usually be judged from the appearance of the fruits (e.g., colour, density and texture), the fruits should be sorted prior to processing: small under-developed fruits are always discarded, fully mature fruits go directly to the next step in the processing chain and immature fruits are put aside for ripening. If necessary, the immature fruits can be graded according to maturity.

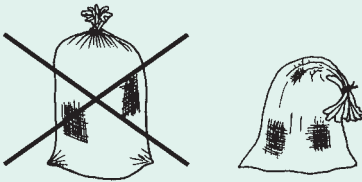
Post-harvest ripening typically takes from a few days to a few weeks. The environment during this period is important in order to control the physiological processes. During the natural maturation process, the water supply to the maturing fruit is regulated through the pedicel and to the seed through the funicle. Continuous evaporation prevents overheating of the embryo while it still has a high moisture content. Maintenance of a high moisture level and avoidance of drastic increases in temperature should simulate these conditions during post-harvest ripening.



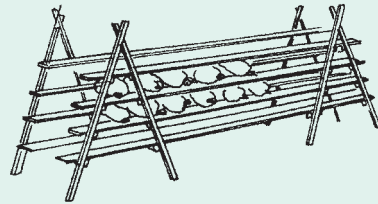
1. Fruits and seeds should be stored under shade and shelter to protect from direct sunlight, heating and rain. If containers are not waterproof, they should be raised slightly to avoid moisture from the ground.



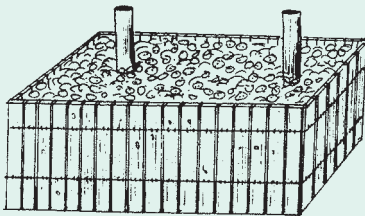
2. Bags and containers should consist of materials that allows maximum air circulation without spilling seed e.g., baskets or hessian bags.



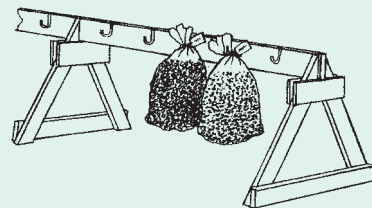
3. Bags and containers are filled to half max-capacity; bags and sacks are tied loosely. This facilitates regular mixing of the fruits and allows expansion of entire fruits such as cones.



4. Fruits and seed should not be piled when moist. Bags should be stored with air space and elevated from the ground to allow adequate ventilation.



5. Large containers may be provided with loosely inserted 'chimneys' to improve ventilation of the inner part of the container.



6. Hanging up bags allows ventilation and gives some protection against foraging animals.

Figure 16.1 Six methods for temporary storage under field conditions (from Schmidt, 2000).

The fruits are kept at normal air temperature. Since the moisture content is high, the fruits are susceptible to fungi. Proper ventilation limits that risk, but may desiccate the seeds too fast. Ripening is concluded when the fruits have reached full maturity. In most dry fruit types, the maturity indices of naturally matured fruits will hold for post-harvest ripened fruits as well. However, since the post-harvest ripened fruits are not normally exposed to sunlight, maturity colours of fleshy fruits may be slightly different from naturally ripe ones, and the fruit flesh may remain relatively firm. To judge when maturity has been reached, examination of seed development and the embryo may be carried out by a cutting test.

In several conifers, rapid drying causes insufficient expansion of the cone scales with consequent difficulties in extracting the seeds. 'Case-hardening' is the situation where moisture is trapped inside the cone because the outer level of the cone dries so quickly that the cells 'collapse' and prevent moisture from the interior migrating to the surface. This may also occur if the cones are not

#### Box 16.2 Safety precautions during processing

**Fire danger.** Dry fruit parts, resin and dust released during processing of dry fruits can easily catch fire and therefore pose a fire hazard (Morandini, 1962). Use of artificial heat or other electric appliances during extraction increases the danger. Dust may catch fire when coming into direct contact with glow wires or the like. Therefore, heat sources should be safely shielded and dust removed regularly during processing. Water and/or fire extinguishers should be readily available at the seed-processing unit.

**Respiratory, eye and skin irritations.** During processing, floral parts, fungal spores, dry pulp and other fine particles become suspended in the air and form what is commonly known as dust. Because dust is dry, it causes general irritation of eyes, nose, and skin with resulting itchiness, coughing, sneezing and allergic reactions. Dust problems can be minimised by appropriate ventilation, possibly by outdoor handling. Extractors should be placed as close to the sources as possible e.g., near threshing machines. Staff working with species or equipment with particular dust problems should be provided with dust masks and possibly also dust glasses.

Some fruits have pulp or seed coats that cause skin irritation on contact. Rubber gloves must be used when handling these fruits.

**Mechanical equipment.** The risk of accidents with mechanical equipment such as threshers and grinders can be greatly reduced by safe construction and maintenance of the equipment and appropriate training and instruction of the operators. Potentially dangerous mechanical or electrical parts (rotating devices, cords, etc.) should be shielded with screens. Screens should be mounted in the front of inlets to e.g., threshers, and operators should observe a safe distance. Emergency switches should be placed near the place of operation so that machines can easily be stopped in case of an accident.

**Poisonous fruit pulp.** Some fruits like *Strychnos* spp. have poisonous pulp, fatal to humans and livestock. Removed pulp and water used for extraction must be discharged and disposed of safely.

given enough space to expand during drying, for instance when they are tightly packed in bags or containers. Re-moistening the fruits, and then exposing them to a second slower drying process normally overcomes the problem (Turnbull, 1975).

Post-harvest ripening of relatively dry fruits may be conducted while the fruits are stored in containers or bags. Alternatively, the fruits may be spread in a thin layer on concrete floors or in trays. In the latter case, it is easier to control the environment. Desiccation may be controlled by regularly spraying with water. Spraying is gradually reduced as the fruits reach full maturity. Fleshy fruits should always be spread out. To allow moisture from softening fruits to drain off, post-harvest ripening in trays is preferable. If the fruits attain maturity at different rates, it may be necessary to manually remove mature fruits in order to avoid decomposition or fermentation of the pulp during the process.

## Seed Extraction

Extraction denotes the procedure of physically releasing and separating the seeds from their enclosing fruit structure. The main rationale of extraction is to:

- a. **Reduce bulk.** This helps to reduce cost of storing and shipment.
- b. **Ease handling.** Seeds are normally tested, pretreated and sown individually, which makes their separation from the fruit necessary.
- c. **Improve storability.** Easily decomposable fruit parts such as pulp of fleshy fruits or arils must be removed to avoid their decomposition during storage. Moisture contained in dry fruit types and cones may attract fungi and insects, especially if stored under ambient temperature. In addition, drying of seeds to a safe moisture content for long-term storage becomes difficult if they are not extracted.

Seed extraction is usually done before storage, but in some species it may be delayed until just before sowing, and in other species the seeds are not extracted, e.g.;

- a. Where storability of non-extracted seeds is better than that of extracted seeds. Reduced storability of extracted seeds may be due to the absence of the protecting structure of the fruit. Further, extraction of seeds of some species is so difficult that it causes physical damage to the seed.

- b. Where labour requirement for extraction is so high that it outweighs possible gain from extraction e.g., ease of handling and germinability.
- c. Where storage facilities, shipment, transport or other handling procedures do not make extraction mandatory.

Most fruit types can be classified as dry or fleshy. During extraction, the former are dried to low moisture content, the latter extracted moist, often after initial soaking in water. A summary of extraction procedures for different fruit types is given in Table 16.2. However, some intermediate types may be extracted as either dry or wet or by two successive procedures.

Fruit type	Extraction procedure
Dry dehiscent (e.g., pods, follicles, capsules and cones)	Drying → shaking/tumbling
Dry indehiscent (e.g., pods)	Drying → threshing
Serotinous (e.g., cones, capsules, dry compound fruits)	Kiln heating → tumbling Scorching → tumbling
Fleshy with very thin pulp	Drying or Soaking → maceration → washing
Fleshy with thick, soft pulp	Soaking → fermentation → washing or Soaking → maceration → washing
Fleshy with soft, fibrous pulp	Soaking → maceration → washing → abrasion/polishing
Fleshy with felty pulp	Soaking → abrasion/polishing

### 1. Dry Fruits

Morphologically, dry fruits are classified as dehiscent and indehiscent fruits. Dehiscent fruits open at maturity to release their seeds; indehiscent remain closed at maturity. This classification is, however, more complex than the definition suggests since there is a gradual transition from indehiscence to dehiscence, which has practical implications for seed extraction. Extraction from dehiscent fruits is influenced by:

- a. **Fruit type.** Dehiscent fruit types are follicles, capsules, cones, dehiscent pods and some compound fruits. Dehiscence is generally related to species, but ease of extraction sometimes varies with subspecies, variety or provenance.

- b. **Stage of maturity at collection.** Fruits picked fully mature are often more likely to dehisce than early-collected ones. The difference may be fully or partly over-come by pre-curing.
- c. **External environment.** Primarily, the moisture content in the fruit determines dehiscence; when the fruit dries out, it splits open. In some fruit types, primarily cones, the moisture content is in equilibrium with air humidity so that when the air is dry, the fruit loses moisture and splits open; when the air is humid the fruit may regain moisture and close again.

## 2. Dehiscent Fruits that Open Upon Drying

Extraction of seeds from dehiscent fruits rarely poses any problems under dry conditions. All that is needed is space to spread out the fruits in a thin layer and sufficient air circulation. This can be done in the field on a tarpaulin or in more permanent drying facilities on concrete platforms, in shelters, or in drying trays and using artificial air circulation and heating. Sun drying and heating should be done with care since high temperatures can damage seeds, particularly those with high moisture content. To avoid overheating, desiccation should be gradual. The fruits may be exposed to a maximum of 35°C until the moisture content of the seeds has lowered to 15%.

The physical release of seeds from dehiscent fruits varies with species and conditions of the fruit. Funicle attachment or physical trapping within the fruit may impede the complete detachment from the fruit. Minor mechanical impact such as raking, shaking or tumbling may be sufficient to complete extraction, however, in some cases threshing or flailing may have to be used.

## 3. Serotinous Cones and Fruits

Serotinous cones and fruits are morphologically dehiscent, but their dehiscence requires an exceptionally high temperature, encountered in nature during bush fires. Serotinous cones occur in some pine species and the scales remain closed due to sealing with resin. During exposure to high temperature, the resin melts and the cones open by the same hygroscopic mechanism as other cones. Many serotinous cones and fruits only open upon exposure to temperatures of at least 70–80°C for several hours. Therefore seed extraction normally takes place in artificially heated kilns. Alternatively, where kiln facilities are not available or in the case of less serotinous fruits, several cycles of drying and wetting at normal temperature usually help to open difficult dehiscent fruits.

Although species with serotinous fruits are adapted to high temperature, too high a temperature or prolonged exposure may be detrimental. To make the seeds less sensitive to heat, it is recommended to pre-dry moist serotinous fruits before exposing them to high temperature.

#### 4. Indehiscent Fruits

Indehiscent fruits must be broken mechanically to extract the seeds. Any mechanical treatment that will split the fruit without damaging the seeds is suitable. For large quantities of fruits, mechanical threshers are normally preferred. Most mechanical threshers work on the same principle as illustrated in Figure 16.2. The thresher consists of a revolving beater mounted within a horizontal cylinder. Fruits are fed from one side and torn apart by the beater. Seed and small fruit parts may pass perforations in the bridge (the concave plate beneath the beater) or the sieve behind, while large material is removed. The seeds are thus pre-cleaned together with the mechanical extraction.

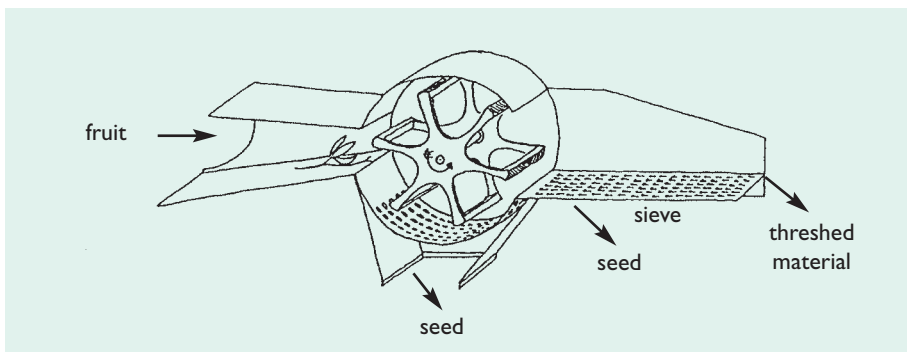


Figure 16.2 Working principle of the flailing thresher (from Stubsgaard and Moestrup, 1991).

#### 5. Fleshy Fruits

Fully mature fruit pulp of drupes, berries and other fleshy fruits often separates readily from the seed. The pulp may be detached manually or by washing. Some species have relatively firm pulp that needs softening to ease seed extraction. Softening occurs during decomposition of the pulp, normally as a result of fermentation. However, heat and possibly alcohol produced by the process sometimes have a negative effect on seed quality. Soaking in water for one or several days often accelerates decomposition, but during prolonged soaking, water must be changed regularly or the container must be provided with a continuous water flow to prevent fermentation damage.

If the fruit pulp has only been partly removed during field handling, the remainder having been dried, the seeds normally need to be soaked or wetted again to remove the remaining pulp at the processing depot.

After soaking or decomposition, the pulp and fruit skin are separated from the seed. Several methods, often used in combination, are applicable.

Selection of the most appropriate method depends on fruit type, quantity of fruit and available equipment. For very small seed lots or seeds with very fragile seed coats, individual manual extraction may be preferable. Larger, less fragile seed lots can be washed and stirred in deep bowls or drums. The heavy seeds will sink to the bottom and pulp and skin will float on the top. If needed, the fruits can be rubbed against a wire mesh before washing. Fruits with fibrous or felty pulp can be mixed with an abrading material like gravel plus excess water and rotated in a drum for various lengths of time. Care must be taken not to over-treat the seeds. The method can also be used for cleaning when most of the pulp has been removed by washing.

Depulping can also be done mechanically, where the fruit pulp is abraded by rupturing and squeezing against or between the mechanical parts of a machine. Two widely used machines are the coffee depulper and the 'Dybvig' macerator (Bowen and Eusebio, 1982; Liang and Yong, 1985; Amata-Archachai and Wasuwanich, 1986; Karrfalt, 1998).

Germination of seeds in fleshy fruits may to some extent be prevented by inhibitory compounds in the fruit flesh. Once the pulp has been removed, the seeds may be able to germinate if the moisture content is high. Therefore, orthodox seeds should be dried quickly. Recalcitrant seed should be dried to the lowest safe moisture level and stored at the lowest safe temperature to prevent germination.

### Box 16.3 Seed damage during processing

Processing always implies a risk of damage or injury to the seeds:

#### **Mechanical damage**

This usually affects the seed coats but occasionally embryos with well developed seed cotyledons. Generally, spherical seeds and small seeds tend to suffer less damage than elongated or irregularly shaped seeds (Bewley and Black, 1994), and dry seeds generally seem more susceptible to mechanical damage than seeds with a high moisture content (More, 1972).

#### **Heat damage**

Heat damage may occur during exposure to sun drying, high kiln temperature for extracting seeds from cones, or deliberate burning for removal of fruit or seed hairs. Fatal high temperature can also occur during fermentation of fruit pulp. Moist seeds are more prone to heat damage than dry seeds.

#### **Chemical damage**

This sometimes occurs during separation by flotation in organic liquids. Other potential sources are fungicides.

#### **Water**

Prolonged submersion in water may be harmful e.g., water softening of the fruit pulp may hamper respiration of the seeds. Prolonged soaking may also cause imbibition and initiate germination in seeds with no dormancy.

## Dewinging

Dewinging, in a broad sense, is removal of any dry fruit appendage, including wings, spines, hairs, and some aril types. Seed (or fruit) wings do not obstruct germination, but may be inconvenient in handling. Accordingly, the main purpose of dewinging is to reduce bulk and ease handling during storage, pretreatment and sowing. In some instances, wings, hair or other appendages, which increase the surface of the seed, tend to collect moisture and promote fungal attack.

The structure of the wing varies between species, from very thin and membranous to hard and woody. In most species there is no abscission zone between seed and wing. Wings can be removed by mechanical abrasion during tumbling with or without abrasion material like sand or gravel, or in a brushing machine where the seeds are rubbed by revolving brushes against the wall of a cylinder consisting of wiremesh (Karrfalt, 1992). For some species, the wings have to be removed manually by secateurs.

## Cleaning Away the Debris

After extraction and possible dewinging, the seed lot typically consists of seeds mixed with inert matter such as twigs, leaf and fruit fragments, soil particles, empty and foreign seeds, dust, small stones and chaff. The aim of seed cleaning is to eliminate all this foreign material to reduce bulk, improve storability and make seeds easier to handle during subsequent processes. The ideal cleaned seed lot consists of all viable seeds of the target species, and is free of any other matter. The degree to which this is achieved is called the purity, usually measured in percentage. A purity of 90% means that 90% (by weight) is seed and 10% is other seed and inert matter.

Cleaning is a separation process. Some cleaning procedures separate the seed lot into only two fractions, one containing the seed and one containing inert matter to be discharged. Other methods may separate the seed lot into several fractions with various purities. Intermediate fractions typically contain both seeds and inert matter and must be further cleaned. Basically, material can be separated from the seed if it differs in physical characteristics like size, form or density. Thus seed cleaning is subject to the trivial precondition that the more the inert matter differs from the seeds in these physical characteristics, the easier it is to separate. The more similar the impurities are to the seeds, the more difficult they are to eliminate. Variation in seed size and morphology of the seed adds another constraint to seed cleaning: the larger the variation in

the seed lot, the more difficult it is to clean. Eliminating inert matter without eliminating viable seeds is difficult for many species. While a purity of say 80% is fairly easy to achieve for most seed, further cleaning can be very hard and laborious. When a certain purity has been achieved, the balance must be considered: either to continue cleaning to achieve a higher purity with the implications of higher processing costs, possible damage to the seeds, and possible loss of viable seeds; or to accept a certain degree of impurity with the implied disadvantages of handling impurities (storage, pre-treatment, sowing, etc.), and possibly a reduced price for the seeds if commercial operation is involved.

Seed cleaning typically consists of a series of processes during which impurities are gradually removed and the seed lot concurrently achieves a progressively higher purity. The type, order, and adjustment of the processes depend on seed type and type of impurities. Cleaning typically starts with a pre-cleaning procedure in which large material such as leaves, twigs and entire empty fruits are removed. This may be done in connection with extraction (e.g., tumbling) and is essential for subsequent cleaning, especially where machines are employed.

The procedures of manual and mechanical cleaning are based on the same principles of separation according to the physical properties outlined above. Despite the higher direct labour cost of manual cleaning, it is often economical for smaller seed lots since it saves time in adjusting and cleaning the machines after each cleaning process. Cleaning large quantities of seeds is more efficiently done by mechanical equipment, especially where combined machines can be used for extraction and cleaning. In some combined machines, the fruits can be fed in one end and the cleaned seed obtained at the other.

The type of cleaning machine must be chosen according to seed type and adjusted appropriately to each seed lot in order to operate efficiently. If the clean-seed fraction still contains too much debris, or the debris too much seed after the first cleaning, the machine should be adjusted and cleaning repeated. Some seed lots may be efficiently cleaned by one cleaning method e.g., sieving or winnowing. If more than one method must be applied, the order is chosen so that as much debris as possible is removed by the first method. This reduces bulk during subsequent processes. An example of a sequence of cleaning is sieving → winnowing → flotation.

Seed lots which are very difficult to clean to high purity e.g., if they contain a large fraction of empty or insect infested seeds with very similar appearance as healthy seeds, can often be cleaned efficiently by initial grading of the seed lot, usually according to size. Once the major portion of debris has been removed by sifting, the seed lot is divided into two, three or more size classes which are then cleaned by one of the other methods. When the individual size classes have been cleaned, they are poured together again into one seed lot. This initial grading avoids size differences interfering with other parameters e.g., specific gravity, and separation consequently becomes much easier in the succeeding cleaning procedures.

## 1. Sieving

Sieving separates material according to size. Objects may pass through an opening larger than their diameter while being retained by an opening of smaller diameter. Asymmetrical objects may pass through an opening larger than their smaller diameter when their small diameter faces the opening. Thus an oblong seed will pass through an oblong hole, while being retained by a round hole.

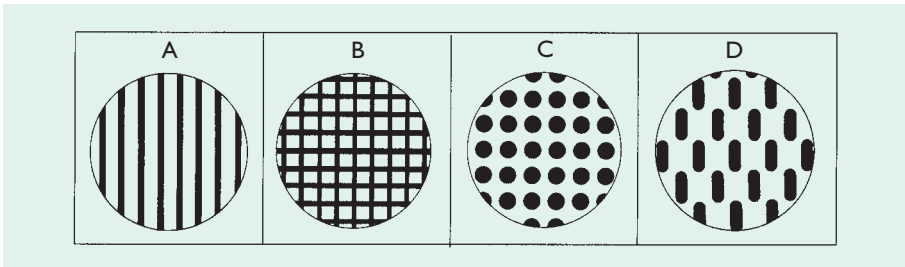
Sieving is typically used for removal of large and small objects from the seed lot. It is also used during fruit cleaning (pre-cleaning) and for seed grading. High purity can be achieved for relatively spherical seeds and objects, whereas it is less effective for flat or winged seeds. The seed lot is sieved through a series of grids with decreasing mesh or hole size. Several types of screens are available. The most common types for small scale cleaning and laboratory use are wire screen grids. Other types, usually used in mechanical cleaners, are metal or plastic sheets or wood boards with different hole size and shape. The choice of screen depends on seed type and quantity. Many types of mechanical seed cleaners with different and replaceable screens are available. Some smaller laboratory seed cleaners may be supplied with more than 100 screens with different hole size and shape. Large industrial cleaners are normally supplied with a smaller number of screens, but screens can be purchased according to the main species processed. Figure 16.3 shows different opening shapes in screens. In general, round holes are used when the items to be separated differ in width (width is the greater diameter of the cross section of the non-symmetrical seed); oblong holes are used when separation is according to thickness (i.e., the smaller diameter) (Karrfalt, 1998).

## 2. Indented Cylinder Cleaning

Sorting according to size is based on the same principle as sieving. Sorting according to length is based on differences in centre of gravity of short and long seeds. When dropped into short pockets in horizontal position on the cylinder, short seeds have their centres of gravity within the pocket and remain there when the cylinder turns, while long seeds with their centre of gravity outside the dent quickly fall out (see Thomson, 1979).

Indented cylinder cleaning is especially useful for separating twig pieces, pine needles and the like from spherical seeds. It is not useful for large seed and seed with large wings or hairs.

The indented cylinder consists of a cylinder with numerous indentations in its inner surface, revolving round a sloping axle. Above the axle and along its length is a fixed sloping trough. During operation, seed to be sorted is fed in at the upper end of the cylinder and slowly moves downward to the lower end. As the cylinder revolves slowly, seeds fitting into the pockets are carried upwards. Separation according to size and length is illustrated in Figure 16.4.



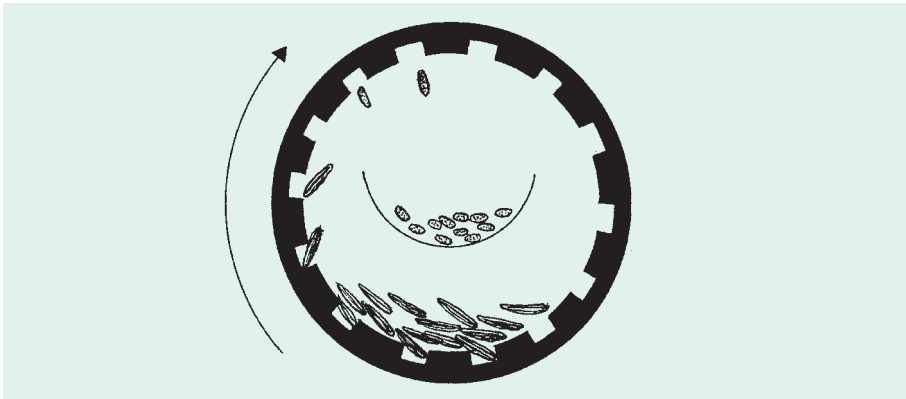
**Figure 16.3** Screens with different hole types used for different seed types in mechanical seed cleaners (from Schmidt, 2000). A) Grid type used mainly for pre-cleaning e.g., branchlets and leaves from large seed. B) Wire mesh type; this screen has a relatively large opening area compared to metal sheets (C–D) and thus allows material through more easily than these. However, the wire mesh more easily gets blocked by material, especially with small opening sizes. C) Metal sheet with round holes, especially used for round seed and for removing large debris (pre-cleaning). D) Metal sheet with oblong holes. Used e.g., for oblong seeds or for separating oblong debris like leaves, fruit stalks, branchlets, and fruit parts. Screens with oblong holes are normally oriented with the holes following the direction of the seed flow (longitudinally).

### 3. Winnowing and Blowing

Winnowing, in its simplest form involves the seeds being held in large flat baskets. The seeds to be cleaned are thrown up into the air, and the wind then blows away light matter like dust, wings and leaf fragments, while the heavier seeds fall back into the basket. This is the traditional way of cleaning grain and can be quite effective for small seed lots. Natural wind displacement can also be used by slowly pouring the un-purified seeds from a certain height into a pile, allowing the wind to blow away light matter while the seeds fall. Since natural wind velocity varies, the method is not always efficient.

Blowing and winnowing separate material according to differences in density (mass/volume) and surface/volume ratio. An object with high density (e.g., a stone) or small surface/volume ratio (e.g., spherical) will fall faster vertically and be moved a shorter distance by a horizontal air current than an object with low density (e.g., wood) or large surface/volume ratio (e.g., a leaf). The method is good for removal of dust, chaff, wings or other light material from seed lots. It is less effective for light, winged seeds.

In the mechanical form, winnowing works with an artificial and, normally, adjustable air stream. Table fans or vacuum cleaners (Gray, 1990) can create simple artificial air currents. More sophisticated cleaners use large fans or propellers. The strength of the air current is adjusted according to seed type and debris. To be separated effectively, the seed must be fully exposed to the air current. There are two variants. The seeds may either pass vertically through the air current, or they may be shaken on an undulating surface over



**Figure 16.4** Indented cylinder cleaning. Separation of short and long seeds. Short seeds are carried upwards into the trough, long seeds fall back into the cylinder (from Schmidt, 2000).

which the air current runs and this elevates them. Normally, the grids on which the seeds are shaken are provided with holes, thus combining winnowing and sifting. Winnowing sorts seed into a gradient with heavy particles (seed) closest to the air source and the lightest farthest away.

The physical principle of air current displacement is also used in seed blowers, which are mainly used for small seed types. The seed lot to be cleaned is placed in a vertical cylinder connected to an electrically powered fan at the bottom that creates an air current. The upwards air current will displace all light material like chaff and wings to the top while the heavier seed are collected at the bottom.

#### 4. Specific-gravity Separators

The separation is, as for the preceding procedure, based on variation in specific gravity and surface/volume ratio. In specific-gravity separators, the seeds and impurities are exposed to forces greater than gravity. The balance between gravity and a force in the opposite direction, will stratify the mixture. The method is used for separation of seeds and objects differing in weight, density and surface characteristics. High precision with consequent high purity can be achieved for many species.

Two variations of specific-gravity separators are available, the oscillating table and the pneumatic table separator.

The oscillating table consists of a slightly inclined table with zigzag partitions along its length. During operation, the table is shaken sideways so that objects placed on the table will be struck by the partitions. Seeds placed in the middle of the table will tend to move downwards by gravity but the strikes on

the partitions will tend to move them upwards. Separation of the seeds is based upon the balance between these two forces. For light seeds, the striking impact of the partitions overcome gravity and hence move them upwards. For heavy seeds the striking impact is insufficient to overcome gravity and the seeds slide or roll downward. The sloping of the table and the sideways movement can be adjusted for different seed types. As the seeds move on the deck during operation, they are also influenced by their surface structure. A surface with high friction is slowed down during movement and follows the stream of heavy seeds.

The pneumatic table separator or specific gravity table consists of a slightly inclined table with a porous surface e.g., a woven linen cloth, connected to a compressed air source. During operation, an air stream is forced up through the table making the seed float on an 'air cushion'. The seed mix will tend to stratify vertically on the 'air cushion' with the heavy seeds at the bottom. Vibrating or oscillating movements of the inclined table inflicts separation. Since the heavy seeds are at the bottom, they will be hit by the surface of the table, which will tend to move them upwards. Hence, light particles will float over the edge of the table at the lower end whereas the heavy particles fall off the table at the upper end.

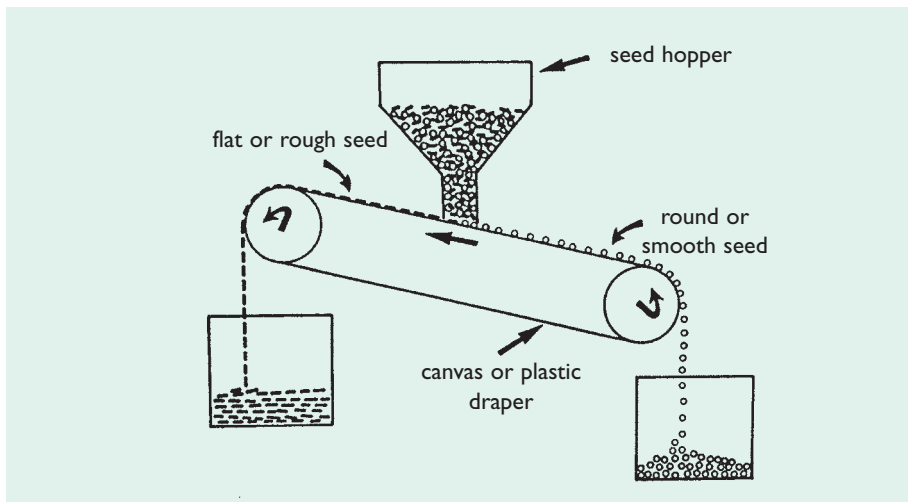
## 5. Friction Cleaning

Shape and surface structure make material slide differently down a slope of high friction material. An object with high surface friction (e.g., a rough leaf) can stay on a steep slope while an object with low friction (e.g., smooth paper) will slide down. Furthermore, an object with a low centre of gravity may stay on the same slope while an object with a high gravity point will roll down. Since spherical objects have both low friction and a high centre of gravity, they will roll down a slope with a relatively small angle. Friction cleaning can be used for separation of seeds that differ in form or surface structure e.g., round seeds to be separated from flat seeds, or smooth seeds to be separated from rough seeds.

Friction cleaning in its simplest form is carried out by letting the seeds move on a sloping cloth frame. Flat objects will remain on the cloth while round objects roll down and are collected at the bottom. In a mechanical derivation of this system, seeds are fed onto a sloping rotating cloth. Round seeds roll down the cloth and are collected in one fraction, flat seeds are carried up the slope into another fraction (Figure 16.5). Feeding of the seed mixture to the separation cloth must be sufficiently slow, so that the seeds can be carried away or roll freely. The rotation speed must be adjusted so that the seeds move smoothly without jumping. The slope is adjusted so that the most effective separation is achieved.

Where the difference is only in surface texture and not in centre of gravity, a vibrator separator is used. The vibrator separates seeds and other matter according to their surface characteristics on a small deck with a rough surface.

A rough surface of the seed will tend to grip the surface of the sloping deck and move the seed upwards when the deck vibrates, while a seed with a smoother surface slides down. Seeds will thus tend to stratify according to their surface characteristic at the outlet end of the table. The vibrator separator has several options of adjustments which can make separation very accurate, *viz.*, 1) the speed of deck vibration, 2) the roughness of the deck (different decks are available with surface ranging from linen to rough sand paper), 3) degree of side and end tilts, 4) the rate at which the seed is fed onto the deck, and 5) the arrangement of the outlet gates (Jensen, 1987).



**Figure 16.5** Friction cleaning. The rotating belt carries small flat or rough particles and seeds upwards, while round or smooth seeds and heavy particles roll down (from Stubsgaard and Moestrup, 1991).

## 6. Flotation

An object placed in a liquid medium will float if its specific gravity is less than that of the liquid, and sink if it has a higher specific gravity than the liquid. Most seeds have a specific gravity below 1.0 when dry and slightly above 1.0 when imbibed. That implies that they will tend to float in water (specific gravity = 1.0) when dry, and sink when imbibed.

Flotation can be used for separation of mature viable seeds from chaff, empty seed, filled dead seed, immature or insect-damaged seed or other particles with a lower specific gravity. While specific gravity differences in air (winnowing, specific gravity separators) may be obscured by surface and volume differences, flotation is independent of the latter. The flotation technique is also applicable if the specific gravity difference between sound seed and inert matter is very small.

### 6.1. Absorption method

Using the absorption method, seeds to be sorted are poured into water. The seeds will initially float, but mature viable seeds will absorb water and sink after some time (from a few minutes to several hours). Empty, immature or damaged seeds and other light material may remain floating and can be skimmed off after an appropriate period of time. Often, however, empty and damaged seeds absorb water at the same rate as sound seeds and will sink accordingly. In this case, the seeds are re-dried shortly (a few minutes to several hours) during which period the empty and damaged seeds will lose water more rapidly than healthy seeds. During a second flotation, healthy seeds sink while immature or damaged seeds float. The mature, sound seeds must be re-dried after separation if the seeds are to be stored before sowing.

The absorption method has been further developed into two practical methods, the IDS and PREVAC methods, that use the fact that sound seed absorbs and desorbs water at a different rate than dead, filled seed and damaged seed. The methods have been developed and used for pines but may be applicable to other species as well.

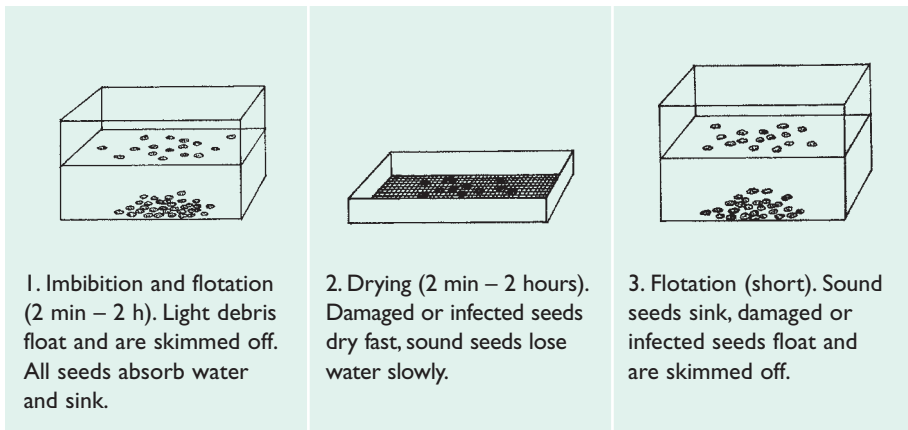
#### *IDS (Incubation-Drying-Separation)*

The method is mainly used as a pre-sowing separation to eliminate seeds that have lost viability during storage. Using the IDS method, the seeds to be separated are initially soaked to allow imbibition, then incubated at optimal germination conditions (e.g., light, optimal temperature and high humidity). After 2–3 d of incubation, the seeds are partially dried, and separated by flotation (Figure 16.6). Seeds with low viability tend to lose water faster during drying than full viable seeds; the seed lot can thus be sorted according to probable seed viability (Bergsten and Sundberg 1990).

The method has one main limitation, *viz.*, that unintentional germination can be difficult to avoid during incubation. This is likely to affect storability and the method should therefore not be used before storage. Germinating seeds are also prone to damage by over-drying after incubation.

#### *PREVAC (Pressure-Vacuum)*

This method is used to separate seeds with mechanical damage from sound seeds. Dry (unimbibed) seeds are exposed to a low pressure (vacuum) for 1 to 20 min while lying in water. When the pressure is released, mechanically damaged seed (e.g., with cracks or part of the seed-coat missing) absorb water more quickly than undamaged seed. During subsequent flotation, damaged seeds tend to sink while undamaged seeds tend to float (Bergsten and Wiklund 1987). Notice that the flotation principle here is the opposite of the one described above in which sound seeds sink.



**Figure 16.6** Principles and procedure of separation by flotation in water by the IDS method (from Schmidt, 2000).

## 6.2. Density method

Liquids with different densities can be used to give a more efficient flotation. A liquid with a specific gravity between those of full and empty seeds (usually below 1.0) is used. Full seeds will sink and empty seeds and light debris float. To work effectively the specific gravity of the flotation medium must be adjusted to a level between the light and heavy material. A number of liquids have been used for separation by liquid flotation e.g., different types of alcohols and ethers (though such chemicals should be used with suitable precautions). A mixture of two liquids with different densities e.g., n-pentane and ethanol, makes a solution with intermediate density; adding a soluble compound to a liquid (e.g., salt to water) normally increases its density. It is thus possible to adjust the density of the liquid quite precisely for optimal separation.

Care should be taken not to leave the seeds in certain media for too long because some flotation media may affect seed viability. It was shown by Simak (1973) that while absolute alcohol had no negative effect on germination, lower concentrations could apparently damage the seed. Barnett (1971) showed that ethanol had a negative effect on storability of some pine species. Short- and long-term effects on viability of other organic flotation media have been documented by Hodgson (1977). The liquid used for separation must obviously be harmless to the seeds. Alcohols are poisonous to seed embryos, but harmless as long as it is only in contact with fruit or seed-coats. Therefore, potential damage is dependent on the liquid itself plus the absorption rate, which in turn depends on the seed-coat structure and the period of exposure. For example, a hard coated species may tolerate short exposure to a poisonous medium, while a longer exposure or a quicker absorption may be detrimental.

## Drying

Normally, all fruits have a variable but high moisture content at full ripeness. Under normal conditions, orthodox species will mature during the dry season allowing the local weather to dry the fruits and seeds. However, to reach the optimal moisture content for storage (normally 6–8%), the seeds mostly have to be dried.

### 1. Drying Rate

The speed of drying is determined by:

*Permeability of the seed coat.* The density and thickness of the seed coat often determine how fast moisture can migrate to the surface of the seed.

*Air velocity.* Drying time is approximately halved when the velocity of the air around each seed is doubled. The upper limits to air velocity are determined by the speed of available fans (or the velocity of natural wind) and the point when the air starts moving the seed. There are also practical limits as to how thin the layer of seed can be.

*Temperature.* A rise in temperature accelerates the drying process. Water evaporates more easily at a higher temperature (a rise of 10°C approximately doubles the speed). In addition, a rise in the temperature also lowers the relative humidity. Many drying processes use a high temperature to achieve a low relative humidity, which again accelerates the drying process.

Note that the maximum temperature that seeds will tolerate depends on the species and how dry the seed is. As a general guideline, 35°C is a safe drying temperature for most orthodox species until the moisture content is below 15%. Below 15% moisture content the temperature can be raised to 45°C.

The air temperature that seeds tolerate also depends on the rate of drying since evaporation cools the seed and, if the energy input is kept constant, temperature of the seeds themselves will be lower than the air temperature.

Furthermore, it should be noted that a high temperature increases respiration and the ageing process in the seed. This implies that the period during which the seed is subjected to a high temperature should be kept as short as possible, by keeping the relative humidity as low as possible and by ensuring sufficient ventilation.

*Relative humidity.* During the whole process, relative humidity of the air should be lower than the equilibrium relative humidity corresponding to the moisture content of the seeds at that stage of the drying process. Equilibrium relative humidities can be determined from sorption isotherms.

*Seed moisture content.* Usually, water is lost rapidly at the beginning of drying. The rate decreases as the moisture content decreases.

## 2. Drying Methods

During drying under controlled conditions, temperature, relative humidity and airspeed can be adjusted precisely to the species/seed lot in question. Where such facilities are not available, drying in the sun or the shade can be alternatives if the climate is favourable.

### 2.1. Drying in the sun

The essentials of sun drying are to avoid shade and ensure as many hours as possible in the sun, to allow free access of the wind to a thin layer of seed, to prevent the seed from absorbing moisture during the night or when the relative humidity is high, to prevent overheating, and to remove any seeds which have separated from fruits and cones during drying.

To avoid absorption of moisture, cover the seed with a tarpaulin against dew, rain and humid air flow, and store indoors or in airtight containers when the moisture content of the seed is so low that absorption cannot be prevented during hours without sun.

To avoid overheating, initiate drying in the shade and transfer the seed to the sun when moisture content is below 15% (see Thomsen and Stubsgaard, 1998).

### 2.2. Drying in the shade

Drying in the shade is advantageous when high temperatures in the sun can damage the seed, if the fruits or seeds need to after-ripen, and for recalcitrant seed where fast drying in the sun is too risky.

There must be adequate ventilation when seed is dried in the shade as high relative humidity will promote fungus and insect attack. Well ventilated, covered walkways or open sheds where driving rain cannot enter are suitable (see Thomsen and Stubsgaard, 1998).

#### Box 16.4 Strategies for control of fungi during seed processing

##### **Avoid or reduce infection through:**

- Seed collection directly from the tree
- Avoiding mechanical damage during processing
- Use of clean equipment
- Removal of dead and damaged seeds

##### **Limit fungal growth through:**

- Removal of dead and damaged seeds
- Temperature and moisture control
- Physical separation of the seeds
- Maintaining optimal seed vigour

(Thomsen and Schmidt, 1999)

**Box 16.5 Maintaining identity during processing**

Two labels should always follow the seed lot during collection. One is placed outside the container, one is put inside together with the seeds. The labels should be written with water-repellent ink and the labels should be resistant to some degree of moisture.

Labels that are no longer valid should be discarded to avoid later confusion e.g., if new labels are written because the old ones become difficult to read, or if several seed lots are mixed.

When fruits or seeds are poured into e.g., trays, depulping or cleaning machines where the label cannot be kept with the fruits or seeds, or where it would be easily lost by wetting or blowing away, the labels should be clipped or stuck to the processing equipment. Once the particular processing part has been concluded, the label is replaced together with the processed seeds.

Partly processed seeds are preferably put into the same containers again. After reduction of the major bulk (e.g., after extraction) fewer, smaller or different types of container may be used. The new containers must be labelled, and redundant labels discarded.

If part of the seed is fully processed and another part needs additional processing, the two parts must be separated and labelled individually e.g., A, B, C....

Discarded labels should be torn or removed completely from the processing site (not just thrown on the floor) in order that they will not later be confused with valid labels.

To avoid contamination with seeds from other seed lots these routines must be followed:

1. The same containers are used before and after part-processing.
2. Emptied containers are thoroughly cleaned before they are used for any other seed lot. Bags are turned inside out to be cleaned in stitching and corners.
3. Processing equipment is thoroughly cleaned after each process. Brushing, the use of compressed air or a strong water current is often necessary for appropriate cleaning.

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