Guide to handling of tropical and subtropical forest seed

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SEED PROCESSING

Contents

Extract from 'Guide to Handling of Tropical and Subtropical Forest Seed'
by Lars Schmidt, Danida Forest Seed Centre. 2000.

Other Chapters of the book Guide to Handling of Tropical and Sub-Tropical Forest Seed by Lars Schmidt soon available on www.dfsc.dk

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SEED PROCESSING

6.1 Introduction

The objective of fruit or seed processing is to achieve clean, pure seeds of high physiological quality (germinability) which can be stored and easily handled during succeeding processes, such as pretreatment, transport and sowing. Processing includes a number of handling procedures, where applicability differs e.g. according to fruit and seed type, condition of the fruits or seeds at collection and potential storage period. Processing can be grouped into the following 7 procedures:

1. Pre-cleaning, for fruit or seed lots containing larger debris, leaves, twigs, empty fruit parts etc.

2. Pre-curing, for fruits that must be after-ripened, or where rapid desiccation hampers extraction.

3. Extraction, for species where the fruits are collected but only the seeds (and occasionally part of the fruit) are stored and sown.

4. Dewinging, for fruits and seeds with wings. Also including removal of dry appendices like spines, arils and hairs.

5. Cleaning, for fruits or seeds with impurities like fruit parts, leaves, twigs, empty seeds, foreign seeds and chaff.

6. Grading, for seed lots with large variation in seed size or weight.

7. Adjustment of moisture content, for seeds which, after the other procedures, have a higher or lower moisture content than considered optimal for storage of the particular species for the expected storage period.

Seed processing normally follows this order, but certain steps may be irrelevant and hence omitted for particular species or seed lots.

Any step in the processing procedure must be carefully adjusted to the particular fruit or seed type. Processing implies a risk of losing seeds both by under and over-treatment. Under-treatment may fail to achieve the desired result (e.g. insufficient extraction of seeds); over-treatment may damage the seeds with consequent loss of viability or reduced storability. Both under and over-treatment may influence the genetic composition of the seed lot (see chapter 12).

Processing should, as far as possible, take place immediately after the fruits or seeds have been brought to the processing depot. Yet, as stated in the previous chapter, temporary storage can rarely be avoided since the processing facilities are often busy during peak collection season. The timely order of processing should give high priority to species and seed lots with easily deteriorating seeds, e.g. fleshy fruits and recalcitrant seeds, or seeds collected with a high moisture content. Processing is not necessarily one continuous process. Partial or intermediate processing, like pre-cleaning, drying or removal of fleshy fruit parts, may typically be undertaken upon arrival to the processing depot in order to impede deterioration during transit. Final processing may then be postponed until later.

Several types of mechanical equipment are available for seed processing. Typically, forest seed processing equipment (as different from agricultural equipment) must be able to adjust to many different seed types. Several types of mainly dry fruits develop large amounts of dust when processed mechanically. In addition to being highly unpleasant dust can cause irritation of skin and respiratory system. Safety precautions and protection of labourers are essential during processing of these species.

6.2. Pre-Cleaning

As during field operations it is essential that equipment and containers are clean, i.e. free from pathogens and seeds of other species, in order to avoid any contamination and possible infection, and that seed lot identity is carefully maintained throughout the operation.

Pre-cleaning is the removal of larger matter such as leaves, twigs and empty fruits. In the field pre-cleaning is undertaken primarily to reduce bulk during transport and storage (see chapter 5). If bulk reduction has not been undertaken in the field, it may be relevant at the processing depot. Redundant bulk inevitably hampers the efficient use of processing equipment, simply because it adds to the volume to be processed.

In some cases pre-cleaning may be necessary to remove material that may impede efficient extraction and subsequent cleaning. For example, twigs left with acacia pods to be threshed for seed extraction break down to size and weight similar to the seed during threshing. The twig fragments are very difficult to separate from the seed during the subsequent cleaning operation (ATSC 1995). In casuarinas the cladodes (scaly leaves) readily fall off the branches when dry and since they are about the same size as the seeds, they make seed cleaning difficult, time consuming and hence expensive. The fruits must therefore be stripped off the branches before extraction (ATSC 1995, Turnbull and Martens 1983).

Finally, leaves, twigs or soil particles may carry fungal spores or other pathogens, which may infect the extracted seeds or germinating seeds and seedlings. An example of the latter is the needle cast disease that affects certain pines. Fungal spores of this pathogen are carried on the dry needles and may from there contaminate the seed lot. The sooner the needles are removed from the seed, the easier it is to control the disease.

Pre-cleaning is usually done manually after arrival at the seed-processing depot. Manual pre-cleaning of seed lots is described in chapter 5, and can be employed for smaller quantities (Turnbull 1975). It may be undertaken during the same process as sorting according to maturity (Bowen and Eusebio 1982, cf. section 6.3). Large quantities of fruits are pre-cleaned mechanically e.g. on vibrating or oscillating screens or in tumblers. The design of pre-cleaning equipment depends on fruit and seed type and the character of debris (twigs, leaves, stones, soil etc.). The principles of cleaning will be described in connection with seed cleaning in section 6.6.

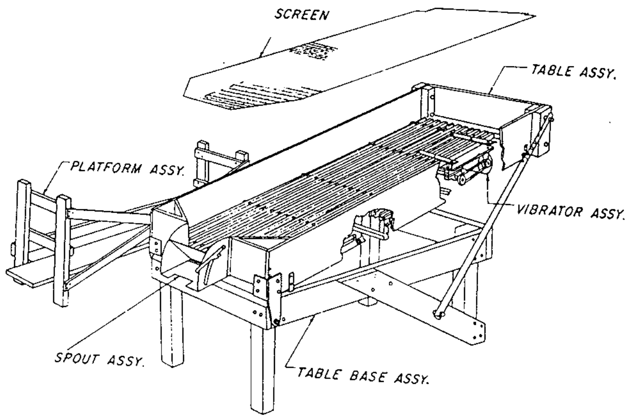


Figure 6.1. Mechanical pre-cleaner with vibrating screen. The pre-cleaner is provided with different screen types for different fruit/cone size. FAO 1967.

6.3 Pre-Curing

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 after-ripening of immature fruits, and 2) to ease extraction of seed where rapid desiccation may cause extraction problems, in extreme cases case-hardening.

Seeds, which deliberately or incidentally were collected immature, must be after-ripened to become physiologically germinable. The physiological background of maturation is discussed in chapter 2.4, the rationale and practical implication of premature collection in chapter 3.2.6. The critical stage after which after-ripening is possible varies between species and must be based on experience. A few species like Ginkgo biloba and temperate Fraxinus species always require after-ripening since the embryo of their seeds is underdeveloped at the stage of dispersal.

During the natural maturation process, the water supply to the maturing fruit is regulated through the pedicel and to the seed through the funicle (see chapter 2). Continuous evaporation prevents overheating of the embryo while it still has a high moisture content. Maintenance of high moisture level and avoidance of drastic increase in temperature should simulate these conditions during after-ripening.

Only fruits that are not mature should be after-ripened. If the seed lot varies in maturity, as can usually be judged from the appearance of the fruits (e.g. colour, see maturity indices chapter 2.4 and 3.2.5), the fruits should be sorted prior to processing: small under-developed fruits are always discarded as they have not attained the capacity to after-ripen. Fully mature fruits go directly to the next step in the processing chain, e.g. extraction; an intermediate portion may consist of mature size fruits capable of after-ripening during a pre-curing period. For example, in Malaysia pods of Acacia mangium are separated into three classes according to colour viz. greenish-brown, brown and black. Greenish-brown pods are after-ripened for 120 hours, brown pods for 72 hours, and black pods go directly to extraction by kiln drying (Bowen and Eusebio 1982). In Thailand pre-curing of Pinus merkusii and P. kesiya is routinely done by storing freshly collected cones in loosely tied gunny-bags or bamboo baskets for 7-14 days (depending on maturity) in a ventilated room or shed before extraction (Granhof 1984, Sirikul 1994). In Kenya seeds of Azadirachta indica, Thevetia peruviana and Ximenia americana are after-ripened for 2-3 days after collection (Ahenda 1991).

After-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. The fruits are kept at normal air temperature, in the tropics between 20 and 30°C. The moisture level is initially high but gradually reduced during the process. The high moisture level during pre-curing makes the seed susceptible to fungal attack. Proper ventilation limits that risk, but carries a risk of desiccation.

After-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 after-ripened fruits as well. However, since after-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.

Pre-curing of cones primarily serves the purpose of easing extraction. 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 layer 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 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).

Seed extraction of several tropical pines can be greatly facilitated by pre-curing, especially for early collected cones. In an experiment of early-collected cones of Pinus elliottii the number of seeds extracted per cone increased from 0 to 60 for cones pre-cured for 1 and 5 weeks respectively. When cones were collected one month later, the number of seeds extracted increased from an average of 27 after 1 week's pre-curing to 82 after 5 weeks' pre-curing (McLemore 1975).

Pre-curing 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 (one fruit thick of large fruits) on concrete floors or in trays. In the latter case it is easier to control the environment during the pre-curing period. Desiccation may be controlled by regularly spraying with water. Spraying is gradually reduced as the fruits reach full maturity.

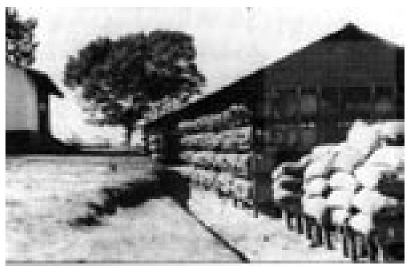
Pre-curing of fleshy fruits should always be carried out while the fruits are spread out. To allow moisture from softening fruits to drain off, the fruits should preferably be pre-cured in open trays. If the fruits attain maturity at different rates, it may be necessary to manually remove mature fruits in order to avoid decomposition or fermentation of the pulp while pre-curing is still going on.

The process of pre-curing is basically the same whether used for after-ripening or to ease extraction. However, since the latter is a mainly physical process, it is less dependent on a physiologically optimal temperature. Consequently the temperature regime is less critical. For example, for cones it may be advantageous to gradually raise the temperature during the later stages of the process (Morandini 1962).

Procedure for pre-curing

- Separate fruits in two or three maturity classes
- Store at ambient temperature at a ventilated place and high humidity; stir regularly to allow ventilation
- Reduce moisture as the fruits approach mature colour
- Conclude the process as the fruits attain mature colour

Figure 6.2.
Pre-curing sheds with open-air racks; Zimbabwe



6.4 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:

1. Reduce bulk. The seeds typically make up 1-5% of the total fruit volume (cf. chapter 5.2). Bulk reduction helps to reduce cost of storing and shipment.

2. Ease handling. Seeds are normally tested, pretreated and sown individually, which makes their separation from the fruit necessary.
3. Improve storability. Easily decomposable fruit parts such as the 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 safe moisture content becomes difficult if they are not extracted.

Seeds are extracted from most multiple-seeded dry fruits such as capsules, pods and follicles and from most fleshy fruit types. In single or few-seeded dry fruits like samaras and nuts, the whole fruit is normally stored and sown, albeit sometimes after removal of e.g. wings or other external structures. In a few fleshy fruits like Vitex parviflora, and arillate seeds of some Podocarpus spp. the whole fleshy unit may be dried and stored. In drupes extraction is only partial as only the fleshy pulp is normally removed, the seed remaining within the dry endocarp. In multiple or compound fruits like Casuarina, Morus and Banksia, extraction is also only partial in the sense that the single-seeded fruits (samaras, achenes or nuts) are extracted from the compound bulky fruit structure.

Extraction is usually undertaken prior to storage, but in some species it may be delayed until just before sowing or omitted altogether, e.g.:

1. Where storability of non-extracted seeds is considerably better than that of extracted seeds.
2. Where labour requirement for extraction is so high that it outweighs possible gain from extraction, e.g. ease of handling and germinability.
3. Where storage facilities, shipment, transport or other handling procedures do not make extraction mandatory.

Re. 1. 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 almost inevitably causes physical damage to the seed. Such damage is likely to affect storability. For example, Cedrus seeds do not store well when extracted and the seeds are therefore normally stored within their fruits, and extracted just before sowing (Stubsgaard and Moestrup 1991). In Melia volkensii the normal storage unit is the depulped drupe (pyrene). The pyrene is very hard and contains 3-4 seeds. In order to extract the seed, the endocarp must be broken, a very arduous manual procedure that inevitably damages some seed. If the damage does not affect delicate parts of the embryo (e.g. the radicle), the seeds may germinate normally if sown immediately. However, even lesser damage is likely to reduce their storability (Kamondo and Kalanganire 1995). In both examples the desired bulk reduction by extraction should be balanced against a likely reduced storability.

Re. 2 and 3. In addition to the possible physical damage to the seed, the process of extraction is often very labour intensive. For samaras like Terminalia brownii and several Pterocarpus species, and for stones of e.g. Melia azedarach no effective extraction methods exist. Despite their bulkiness and possible delayed germination, seeds of many hard fruited species are not fully extracted but stored and sown together with the enclosing fruit.

Extraction may, as in the case of Vitex parviflora, Melia volkensii and Pterocarpus spp., be carried out just prior to sowing. Since the purpose of such post-storage extraction is to promote germination, it is in seed handling context equivalent to pretreatment and is discussed as such in chapter 9.

Table 6.1.
Examples of different storage units in different species

Seeds normally extracted before storage	Most species, e.g. most conifers, casuarinas, eucalypts, and species of the families Leguminoseae, Meliaceae, Bignoniaceae .
Seeds normally stored and sown together with the entire fruit	African *Terminalia* spp., *Quercus* spp. and dipterocarps
Seeds often or occasionally stored within fruits but extracted before sowing	*Vitex parviflora*, *Maesopsis eminiii*, *Grewia* spp., *Pterocarpus* spp.

Most fruit types can be classified as dry or fleshy (chapter 2). During extraction the former is dried to low moisture content, the latter extracted moist, often after initial soaking in water. A summary of extraction procedures appears from table 6.2. Some intermediate types may be extracted as either dry or wet or by two succeeding procedures. For example, some Prosopis spp. are first extracted from the pod by dry extraction i.e. drying and threshing; the enclosing pulp is then removed by washing. In Afzelia africana the enclosing aril may be removed by washing after dry extraction of the seeds from the pod. In many-seeded drupes like Melia azedarach depulping is carried out according to the procedure for fleshy fruits, while an extraction procedure for dry fruit must be used if the seeds subsequently are extracted from the stone.

Table 6.2.
Summary of extraction methods for various fruit types

Fruit type	Extraction procedure
Dry dehiscent fruits, e.g. dehiscent pods, follicles and capsules and cones, e.g. pines, eucalypts and most Leguminosae	Drying → shaking / tumbling
Dry indehiscent fruits, e.g. indehiscent pods of *Acacia nilotica* and *A. siberiana*	Drying → threshing
Serotinous fruits, e.g. cones, capsules plus some dry compound fruits	Kiln heating → tumbling Scorching → tumbling
Fleshy fruits w/ very thin pulp, e.g. *Vitex* spp. and *Ziziphus* spp.	Drying Soaking → maceration → washing
Fleshy fruits w/ soft pulp, e.g. *Prunus, Olea, Ficus*	Soaking → fermentation → washing Soaking → maceration → washing
Fleshy fruits w/ soft, fibrous pulp, e.g. *Gmelina*	Soaking → maceration → washing → abrasion / polishing
Fleshy fruits w/ felty pulp, e.g. *Tectona grandis, Sclerocarya* spp. and *Vitex* spp.	Soaking → abrasion / polishing

6.4.1 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 (chapter 2.5). 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:

1. Fruit type. Dehiscent fruit types are follicles, capsules, cones, dehiscent pods and some compound fruits (chapter 2.5). Dehiscence is generally related to species (e.g. dehiscent pods of Acacia mellifera, indehiscent pods of A. nilotica), but ease of extraction sometimes varies with subspecies, variety or provenance.
2. 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 overcome by pre-curing.
3. External environment. Primarily the moisture content in the fruit determines dehiscence; when the fruit dries out, it tends to split open. In some fruit types, primarily cones, the moisture content is in equilibrium with air humidity such that when the air is dry, the fruit loses moisture and splits open; when the air is humid the fruit may re-gain moisture and close again. The process is hence reversible.

Dry fruits are normally handled according to degree of dehiscence. Four groups are recognised.

a. Dehiscent fruits that open upon drying
b. Serotinous cones and fruits
c. Indehiscent fruits where seeds are extracted
d. Indehiscent fruits where seeds are not extracted

a. Dehiscent fruits that open upon drying

Many dehiscent fruits open readily when dry, and extraction of their seeds rarely imposes any problems under dry conditions. Examples of some easily extractable seeds are species of Eucalyptus, Callitris, Casuarina, and many conifers. Often seed extraction of these species can be done easily in the field (chapter 5). All that is needed is space to spread out the fruits in a thin layer and sufficient air circulation. Techniques recommended for drying in the field (section 5.6.1) hold for the processing depot as well. Dry processing at the processing depot can, however, be provided with more permanent drying facilities, e.g. concrete platforms, shelters, drying trays and possibly artificial air circulation. Some of these facilities are summarized in appendix A6.1.

Most dehiscent cones open readily when their moisture content (m.c.) falls to 20-25% and are fully opened at a moisture content of 10-15% (Stubsgaard and Moestrup 1991). For most species, 15% m.c. is equivalent to a relative air humidity (RH) of around 70% (see appendix A5.2). Under humid conditions as in the ever-humid tropics or during the rainy season, RH rarely comes below 70% in the shade.

Under these conditions it can be a problem to bring down the m.c. of the fruits with concurrent dehiscence. Direct sun drying is an option that should be handled with care since temperatures in the sun may easily reach 45-60°C, a critically high level for seed with a high m.c.

Temperature can be raised with concurrent improvement in drying effect by covering e.g. extraction trays with transparent polythene sheets (Granhof 1984, Sirikul 1994, see fig. 6.3). The risk of detrimental overheating of moist seed is the same as for direct sun drying, and high temperatures should be applied only when the fruits have lost most of their moisture.

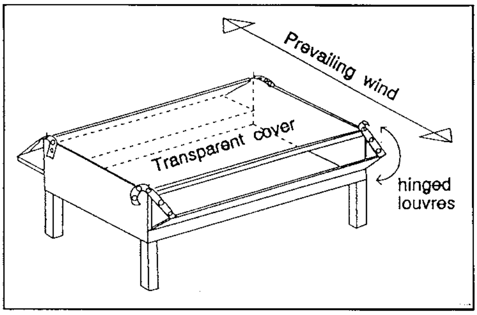


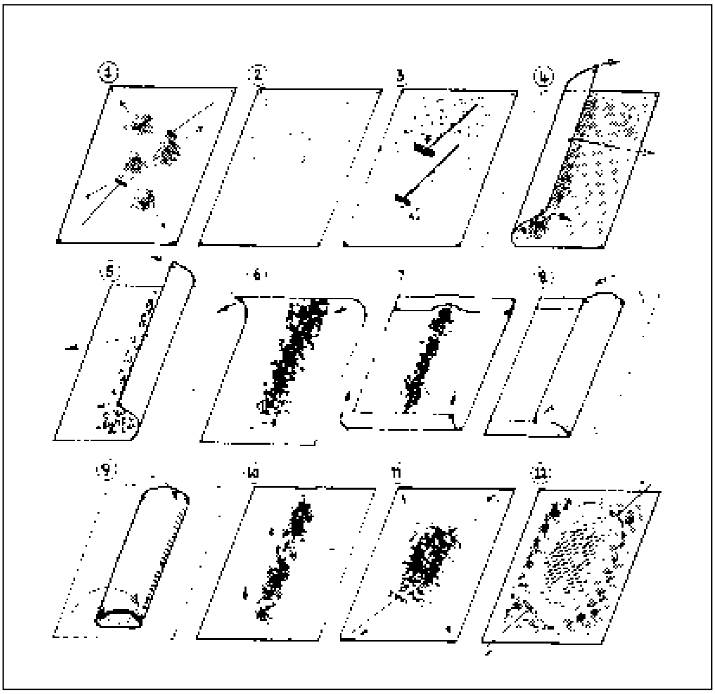
Figure 6.3. Drying fruits in a tray covered with a transparent polythene sheet. The temperature rises under the sheet with concurrent decrease in RH. Moisture evaporated from the fruits must be removed by appropriate ventilation. Appropriate ventilation (on windless days e.g. provided with a fan) is also necessary to prevent overheating.

To avoid overheating, desiccation should be gradual. The fruits may be exposed to a maximum temperature of 35-40°C until the moisture content of the seeds has lowered to 15-20% (seeds must be extracted manually and the moisture content checked e.g. by a moisture meter, see appendix A5.3). After that the temperature may be raised e.g. by sun or kiln drying. For immature and moist material of most Australian species, ATSC (1995) recommends an initial drying for two days at 25°C, then increasing to 35°C. The low initial temperature helps minimise the risk of fungal activity destroying the seeds.

Outdoor drying is feasible for many dry fruits during the dry season. The fruits may be dried on concrete platforms, tarpaulins or permanent drying shelters. Because of the reversible character of dehiscence, it is sometimes necessary to prevent the fruits or cones from re-absorbing moisture when the air humidity rises, e.g. at night. The fruits may be covered (see fig 6.5) or moved indoor, whenever there is a risk of regaining moisture.

Figure 6.4. Drying shelters for seed extraction of pines; Zimbabwe.

Figure 6.5.
Drying cones and fruits on tarpaulins. The tarpaulins are 5x5 or 5x10m in size, and made of thick waterproof canvas. During drying the tarpaulins are spread out on the ground with good drainage, exposed to the sun but protected from the wind blowing away tiny seeds. The cones are spread out on the tarpaulin in a thin layer and turned regularly to ensure uniform drying. Every night or during rain the tarpaulin is folded over the fruits. This method has been used for drying and extraction of seeds of Pinus oocarpa and Pinus caribaea in Honduras (abbreviated from Robbins 1984).



In cases where air humidity is too high or where frequent showers make sun drying impossible or impractical, the fruits must be kiln dried. Kiln drying is used for most temperate cones. In kilns the temperature is raised above ambient air temperature by solar or artificial heating. To assure uniform drying the fruits are regularly stirred or moved during kiln drying. Kiln drying may be combined with tumbling by providing the tumblers with a heated air stream. Some kiln types and their use are presented in appendix A6.1.

The physical release of seeds from dehiscent fruits varies with species and condition of the fruit. Funicle attachment or physical trapping within the fruit may impede the complete detachment from the fruit. Capsules of *Swietenia* and *Entandophragma*, and cones of *Abies*, *Araucaria* and *Agathis* normally disintegrate completely upon drying. In some species a minor mechanical impact such as raking, shaking or tumbling is sufficient to complete extraction. That goes for e.g. *Markhamia platycalyx*, *Spathodea nilotica* and other *Bignoniaceae*, and many conifers. In eucalypts the release of seeds depends upon the position of the ovaries. Species with half-superior ovaries like E. camaldulensis release their seeds more easily than those with inferior ovaries, e.g. *E. delegatensis* (Boland *et al.* 1980). Chaff in the capsules can be a physical constraint for the release of seeds in eucalypts. Seeds of some species maintain a strong attachment to the fruits via the funicle after dehiscence. That goes especially for dehiscent legumes like *Acacia*, *Albizia*, *Acrocarpus* and *Paraserianthes,* which are naturally dispersed attached to half of the dehiscent pod. The mechanical release may be accomplished by tumbling or shaking, e.g. together with pre-cleaning of the seed. If the attachment is very strong, the seeds may need to be extracted by the methods of indehiscent fruits, e.g. by threshing or flailing (see below).

Fruits of normally dehiscent species may fail to open if collected immature. For example, greenish and light brown pods of *Acacia mangium* often retain a significant number of seeds after pre-curing and threshing. Kiln drying may be able to open the fruits (Bowen and Eusebio 1982).

Capsules and cones attacked by insects or fungi may occasionally fail to open appropriately, either because web or fungal hyphae physically obstruct seed release, or because the infection obstructs the normal opening mechanism. Seeds from such fruits can only be extracted by threshing.

b. Serotinous cones and fruits

Serotinous cones and fruits are morphologically dehiscent, but their dehiscence requires an exceptionally high temperature, in nature encountered during bush fires. Serotinous cones occur in pine species like *Pinus taeda*, *P. brutia*, *P. halepensis* and *P. contorta*. In these species the cone 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. Serotinous fruits also occur in some angiosperms from fire prone areas, e.g. some *Eucalyptus*, *Casuarina*, *Banksia* and *Hakea* species. 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. Kiln drying at 70°C for 18 hours was found suitable and did not hamper viability for pre-cured Acacia mangium seeds (Bowen and Eusebio 1982).

A brief exposure of max 1.5 min to super-high temperature of 220°C provided by a gas flame was found a suitable alternative to prolonged kiln drying for extraction of seeds of *Pinus contorta* var. *latifolia*. Longer exposure seriously hampered viability (Wang *et al.* 1992).

In Australia fruits of *Banksia* and other extremely hard fruits are opened by placing them on a wire mess over hot coal until they split open. When the fruits have opened, they are immediately immersed into water and then sun dried (Kabay and Lewis 1987, Gray 1990). Short dipping in boiling water for 5 sec. to 10 min has been reported to ease opening during subsequent kiln drying for some species. Alternatively, where kiln facilities are not available or for 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 temperatures or prolonged exposure may be detrimental. It should be reiterated that high moisture content in the seeds makes them more sensitive to heat. Therefore, pre-drying of moist serotinous fruits should be undertaken before exposure to high temperature. This will also prevent the above-mentioned case-hardening.

c. Indehiscent fruits where seeds are extracted

Indehiscent pods of e.g. *Acacia* and *Prosopis spp*. will not open by drying alone, but must be broken mechanically in order to extract the seeds. Initial drying or heat treatment promotes brittleness of the pods, which will facilitate subsequent extraction. For Australian species drying at 40-45°C for 24 hours has been recommended (ATSC 1995). Seeds from large fruits like Parkia biglobosa may be extracted by individually splitting each fruit by hand (Some et al. 1989). Most smaller indehiscent pods may be broken-up by beating or flailing, crushing them in a mortar, rolling over them with a drum, threshing or tumbling in a cement mixer with blocks of heavy wood (Bowen and Eusebio 1982). Any mechanical treatment that will split the fruits without damaging the seeds is suitable. Some simple methods of extraction were mentioned in section 5.6.2. Where large quantities of fruits are to be processed, mechanical threshers are normally preferred.

Most mechanical threshers work on the same principle, as illustrated in fig. 6.6. 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 larger material is removed. The seeds are thus pre-cleaned together with the mechanical extraction.

The most commonly used thresher type for forest seed is the flailing thresher, which is used e.g. for several Australian *Acacia* species (Doran *et al.* 1983). Mechanical threshers designed for agricultural crops are available in most parts of the world. They are normally designed for grass crops like rice or grain and usually need some modification to be used efficiently for woody material.

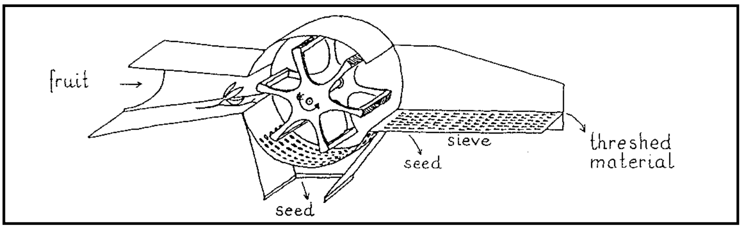


Figure 6.6.
Working principle of the flailing thresher (from Stubsgaard and Moestrup 1991). See also fig. A6.3 in appendix 6.

For species with very hard pods like *Acacia nilotica* and some *Prosopis* species, threshing is insufficient to break the pods. Grinding mills have been used successfully for some of these species. The grinding stones or steel are adjusted to a distance slightly larger than the seed. Hammer mills work in principle like a flailing thresher, where the beater is replaced by a revolving steel cross pulverising the material against the drum. It can be used for threshing hard fruits if the revolutions of the hammer are reduced to 250-800 per minute and the outlet screen is replaced by holes that will let the seeds out (Stubsgaard and Moestrup 1991).

In species like several *Prosopis spp.* the seeds are embedded in a pulpy material, or the pod contains gummy material which is difficult to break up mechanically. These species must be treated in a series of steps (Bonner et al. 1994):

i. Breaking the pods
ii. Soaking in 0.1N hypochloric acid for 24 hours

iii. Washing and drying
iv. Pounding the dry material with a hammer or in a mortar.

Pods with gummy material (e.g. Prosopis cineraria) may need several rounds of threshing with intermediate drying, or the pods may be run through a coarse meat grinder to extract the seed (Bonner et al. 1994).

Seeds of indehiscent pods of acacias are adapted to being ingested by animals; their seed-coats are very hard and are rarely damaged by mechanical extraction. Other seeds are more delicate and mechanical treatment should be limited as much as possible. Seeds that have been extracted are more susceptible to physical damage than those still retained within and protected by the fruit. It is important, therefore, that seeds are removed from the fruits soon after their release. In some instances 2-3 rounds of threshing with intermediate removal of extracted seeds are better than one complete threshing at high speed.

d. Indehiscent fruits where seeds are not extracted

Seeds in samaras of e.g. *Pterocarpus*, *Combretum* and *Terminalia* are not normally extracted but remain within the fruit at least until sowing. Nuts of *Quercus*, *Fagus* and *Castanea* are usually extracted from their involucre or cupula by drying or tumbling. Dipterocarps are not extracted.

6.4.2 Fleshy fruits

Fully mature fruit pulp of several drupes, berries and other fleshy fruits often separates readily from the seeds. The pulp may be detached manually or by washing as described under pre-processing in chapter 5. Other species like *Azadirachta indica*, *Aleurites spp.*, and *Santalum spp.* have relatively firm pulp that need softening to ease seed extraction.

Softening occurs during decomposition of the pulp, normally as a result of fermentation. Controlled fermentation can be used effectively as a pre-extraction procedure for several species e.g. *Dovyalis*. However, heat and possibly alcohol produced by the process sometimes have a negative effect on seed quality. Seeds extracted from fermented *Gmelina arborea* drupes have shown a markedly reduced germinability as compared to seeds extracted mechanically from fresh fruits (Liang and Yong 1985).

Soaking in water for one to several days often accelerates decomposition of the pulp, especially for fruit types with relatively dry pulp, e.g. *Ziziphus mucronata* and some *Diospyros* species. Soaking for several days has been recommended for e.g. *Santalum spp.* the pulp of which is generally difficult to remove (Gray 1990). Mechanical rupture of fruit skin prior to soaking often speeds up softening and decomposition (Albrecht 1993). 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. During prolonged soaking of several days, water must be changed regularly e.g. once every 12 hours, or the container with fruit must be provided with a continuous water flow to prevent fermentation damage.

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 fruits to be processed and equipment available:

1. Individual manual extraction. Entirely manual extraction may be applicable to very small seed lots, seeds with extremely fragile seed-coats (e.g. *Syzygium cumini*), or large fruits where mechanical equipment cannot be efficiently used. The latter category encompasses many humid tropical species like *Artocarpus and Durio* spp. Individually extracted seeds may be washed and cleaned as outlined below.

2. Washing in deep bowls or drums. This may be a simple continuation of soaking and applicable if the pulp separates easily from the seeds or stones, *Melia volkensii*, *Dipteryx panamensis*, *Prunus africana* and others. Mechanical stirring or using a strong water stream while the fruits are submerged in water help to loosen the pulp. If pulp sticks to the seeds or stones, vigorous stirring or increased water pressure is necessary. Small seed lots and small seeds may be extracted effectively by the aid of a blender used at low speed or an electric mixer. Separation of pulp + skin and seeds is done by flotation in excess water: seeds or stones remain at the bottom while pulp and skin tend to ascend to the surface where they may be skimmed off. In some species very clean seeds can be achieved by washing, in others washing may be used as a pre-extraction procedure.

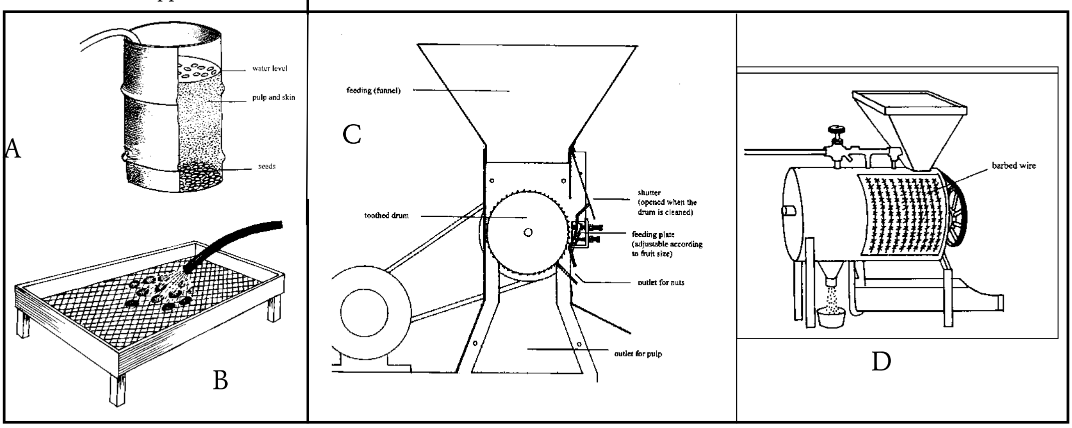
3. Washing on wire mesh screens. Screens with mesh size that will retain the seeds while the pulp passes through are used. The pulp is released by manually rubbing the fruit against the grid and washing. High water pressure should be avoided because of the risk of washing away seeds. Fruit skin and firm fibres of the fruit flesh are normally retained with the seeds or stones after rubbing and washing. They may be separated by flotation in excess water as described above. The method is widely applicable to most fleshy fruit species, and the safest and most efficient procedure for extraction of very small seeds or seeds with fragile seed-coats. Since the fruits are rubbed manually on the screen, the mechanical impact can easily be adjusted when extracting fragile seeds. To separate pulp from tiny seeds, fine mesh screens must be used. In the Philippines a 1/16 inch mesh was used for seed extraction of Anthocephalus cadamba (Seeber and Agpaoa 1976). If high-pressure water is available, a modification of this method is to place the fruits in wire mesh bags with mesh size just below the seed or stone size. The water pressure is then directed directly against the fruits, which may be cleaned completely by the water pressure. This method has been used to clean seeds of e.g. Prunus and Vitis spp. (Bonner et al. 1994).

4. Cement mixer with abrading material. The fruits are mixed with an abrading material like gravel plus excess water and rotated in the drum for various lengths of time, typically from 5 to 20 min.

While the abrading material rubs against the fruits, the pulp is gradually torn off. The fruits are checked regularly in order to avoid unnecessary overtreatment with possible damage to the seed-coat. Cleaning becomes more difficult with this method since the mixture must be separated into three fractions after extraction, viz. seed, abrading material and fruit pulp. The method may be used as the only depulping method; more often, however, it is used as a final cleaning after the major part of the pulp has been removed e.g. by washing. The risk of mechanical damage is relatively high and the method hence less applicable to seeds with fragile seed-coats. Tumbling in a cement mixer with blocks of wood has been used in Kenya for species with sticky pulp e.g. Vitex keniensis, Maesopsis eminii and Cordia spp. (Ahenda 1991).

5. Mechanical depulping. For large quantities of fruits or where the flesh tends to remain firm, mechanical depulping is applicable. In the tropics the most widely used mechanical equipment is the coffee depulper, or a modified version thereof (Bowen and Eusebio 1982) (see fig. 6.7C and fig. A6.6). The depulper mechanically abrades the fruit pulp by rupturing and squeezing against or between its mechanical parts. Because of the risk of mechanical damage, the depulper is particularly applicable to fruits with relatively hard seed-coats or stones, e.g. most drupes. A slightly modified version of the ordinary coffee depulper has been used effectively for Gmelina arborea (Liang and Yong 1985). Another widely used mechanical depulper is the 'Dybvig' macerator (Amata-archachai and Wasuwanich 1986). In this depulper the fruit pulp is abraded on a flat spinning plate provided with four bars arranged in a 90 degree cross at the bottom of a cylinder (fig. A6.7). A continuous water stream helps to wash away the separated fruit pulp. The standard model of the 'Dybvig' macerator has been improved by lining the inside of the cylinder with a wire net and bolting a can, also lined with wire net, to the spinning plate (Karrfalt 1998). In this way the fruits are squeezed and ruptured between the two rough surfaces of the cylinder and the bolted-on can.

Figure 6.7.
Equipment used for depulping of fleshy fruits. A) Drum for softening of pulp and separation by flotation. The fruits are left soaking in the water 1-2 days and occasionally stirred to loosen the pulp. The floating pulp and skin are skimmed off. B) Wire screen mesh. The fruits are ruptured on the screen and washed by water current. C) Coffee depulper. The fruits are depulped mechanically by the revolving drum. D) Teak fruit treatment machine. The drum is wrapped with barbed wire to abbrade the felty pulp (redrawn from Bapat and Phulari 1995). See also appendix A6.1.



In some species, fibrous fruit flesh tends to remain attached to the endocarp or seed-coat after washing. These remnants may be removed by abrasion, polishing or brushing (fig. 6.8). Dry or moist tumbling with sand or other abrading material in a cement mixer is effective, but may damage sensitive seeds. Seeds of Gmelina arborea have been successfully cleaned for residual pulp by polishing them in a coffee dehusker (Liang and Yong 1985, Bowen and Eusebio 1982). See also biological extraction, section 6.4.3.

In teak (*Tectona grandis)* the mesocarp is felty rather than fleshy, and its removal requires a relatively vigorous treatment. In India a depulping machine with a drum tightly wrapped with barbed wire was found suitable (Bapat and Phulari 1995) (fig. 6.7D).

Depulping of species with extremely sticky fruit flesh, e.g. some Euphorbiaceae like *Antiaris toxicaria* and *Bishofia javanica* may be facilitated by adding some detergent or alkaline to the water during tumbling, e.g. 1 N hypochlorite. Cleaning of equipment after extraction should be done with a similar detergent, but the concentration may be increased.

Germination of seeds in fleshy fruits may to some extent be prevented by inhibitory compounds in the fruit flesh (see chapter 9 and 10). Once the fruit 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.

6.4.3 Biological extraction

Fleshy fruits and several indehiscent dry fruits are adapted to being ingested by animals (section 2.6). Seeds and stones are often left cleaned and intact after ingestion although in some species a relatively large amount of seeds may be digested.

Feeding legume pods to domestic goats may serve the purpose of extracting seeds from the fruits, but implies a subsequent workload in collecting the droppings and then extracting the seeds. The procedure can be rather laborious, but ingestion usually scarifies the seeds so that labour may be saved on pretreatment (see chapter 9). Accumulated manure in goat enclosures in areas with heavily fruiting *Acacia nilotica* and *A. tortilis* often contains large amounts of seeds from these species (section 4.6).

Seeds can be extracted from manure by wet or dry extraction. During dry extraction the manure is initially dried and fractioned e.g. by gentle pounding in a mortar or the like, then cleaned by tumbling and sifting. During wet extraction the manure is soaked and washed in water. The seeds that gather at the bottom of the container are then separated by sifting under running water. Wet extraction gives the cleanest seed, but if scarified by the ingestion, the seeds may readily imbibe, which may make them sensitive to further treatment. A problem of collecting the seeds from manure is that the manure often contains a mixture of seeds from different species which can be difficult to separate.

Both ants and termites may readily and efficiently clean fruits and seeds of sweet material, both moist and dry. In the Philippines, termites will readily attack pods of *Samanea saman* piled up in a dark place. The termites consume the fruit parts only, and after a short time the seeds will be left clean (Seeber and Agpaoa 1976). Termites also attack fruits of Kigelia (sausage tree), the seeds of which are very difficult to extract except manually. However, although it is primarily the soft fruit that is consumed, many seeds are also lost. In Brazil, ants have been reported to efficiently remove pulp from pods of *Hymenaea courbaril* (Caesalpinaceae) which also promoted germination of the seed (Oliveira *et al.* 1995). Termite extraction is generally not a good idea close to buildings and inside nursery premises. The indirect feeding may both attract and assist them to multiply, which may give problems later. Ants are less problematic and may be used for final cleaning of residual adherent pulp.

6.5 Dewinging

De-winging, in a broad sense, is removal of any dry seed 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, hairs or other appendices, which increase the surface area of the seed, tend to collect moisture and promote fungal attack. Dewinging is often done as a routine before storage or shipment, while seeds sown immediately after collection, e.g. dipterocarps and other recalcitrant species, rarely have their wings removed.

Wings and hairs occur in wind dispersed species (chapter 2). Wings are typical of indehiscent dry fruits like samaras of *African Terminalia spp., Pterocarpus, Triplochiton, Heretiera, Kokoona, Casuarina* and many others. Winged seeds occur in many Meliaceae (e.g. *Cedrela, Chukrasia, Khaya, Swietenia*) and Bignoniaceae (e.g. *Markhamia, Tabebuia, Tecoma* and *Spathodea*), and prevail in conifers.

The structure of the wing varies from very thin and membraneous in Bignoniaceae, casuarinas and most pines, to hard and woody in most samaras. Attachment of seed wings to the rest of the seed varies in strength and morphology, and dewinging procedures vary accordingly. The wings of pines are of a type that clasps the seed and is normally lost before germination, usually after wetting. In most other species there is no abscission zone between seed and wing, and most of the wing remains attached to the seed during germination.

Seeds with hairs (floss) occur mainly in Bombacaceae (*Bombax* and *Ceiba* (Kapok)) and Salicaceae (*Salix* and *Populus spp*.). In some *Pterocarpus* spp. the samara has thin spines.

Wings of conifers are removed by mechanical abrasion during tumbling. Slight wetting by spraying e.g. 1 litre of water to 50 litres of seed during tumbling often facilitates dewinging. Special mechanical dewingers are available where wings are abraded between brushes. Some species like *Abies* spp. have delicate seed that are easily damaged during dewinging (Edwards 1981). These species are preferably dewinged by tumbling in closed drums where the mechanical impact is reduced by slow revolutions where seeds rub against each other. Casuarinas and other species with papery wings may be dewinged by tumbling in cement mixers together with some abrasion material like sand or gravel. The same procedure may be used for removing hairs and spines. If the seeds are mixed with abrading material, it is important that this can easily be removed from the seeds after tumbling and that it does not damage the seed. Abundant hair like that in kapok may be removed by burning.

A very efficient machine for dewinging and detachment of dry appendices such as hairs, floss, arils, floral or fruit parts from the seed is the brushing machine shown in fig 6.8. During operation the seeds are rubbed by revolving brushes against the wall of a cylinder consisting of wire mesh. Rotation speed, distance between brushes and cylinder, type of brushes and mesh wall of the cylinder can be adjusted according to seed type and wing or appendix to be removed (Karrfalt 1992).

Large winged seeds like *Swietenia*, *Entandophragma* or *Triplochiton* spp. are dewinged manually by breaking off the wing by hand or cutting it with secateurs.

Samaras with very hard fruit coats like *Terminalia brownii* and *Pterocarpus* spp. often require a very fierce treatment if wings are to be removed. Some seed processing units have successfully used coffee dehuskers or hammer mills.

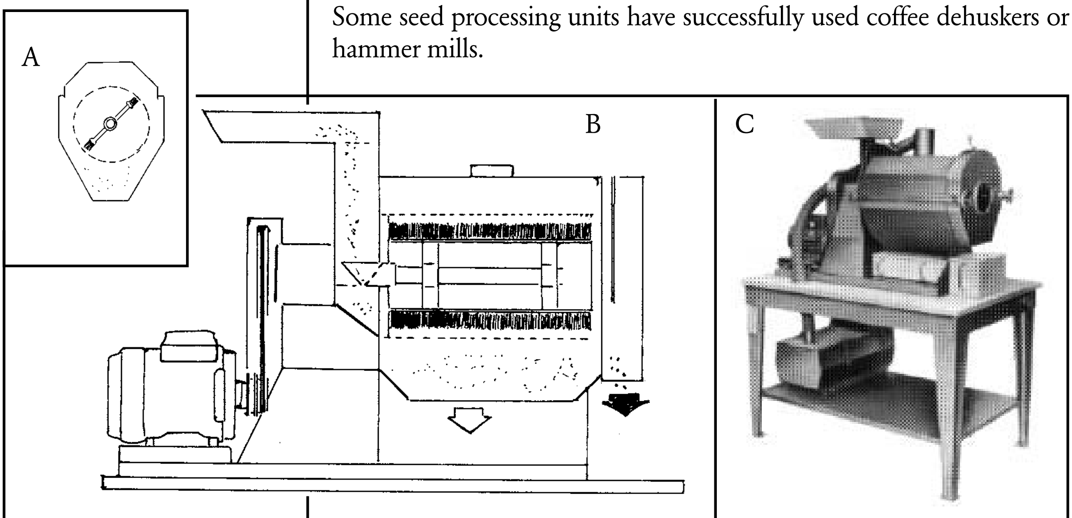


Figure 6.8. Working principle of brush type dewinger. A. Transverse section. B. Longitudinal section. The seeds are rubbed against the wire cylinder (shell) by two (in some types four) rotating brushes. The de-winged or de-flossed seeds pass through the opening in the wire cylinder together with removed wings, hairs etc. (re-drawn from Jensen 1987). C. An example of a laboratory brush machine.

6.6 Cleaning

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, chaff and the like. 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 from 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% is seed and

10 % is other seed and inert matter (see chapter 11). Some cleaning methods are also used during the process of grading or upgrading in which both germination and uniformity of the seed lot are increased by removing a fraction of seeds of the same species usually the smallest and those with no or poor viability (see section 6.7)

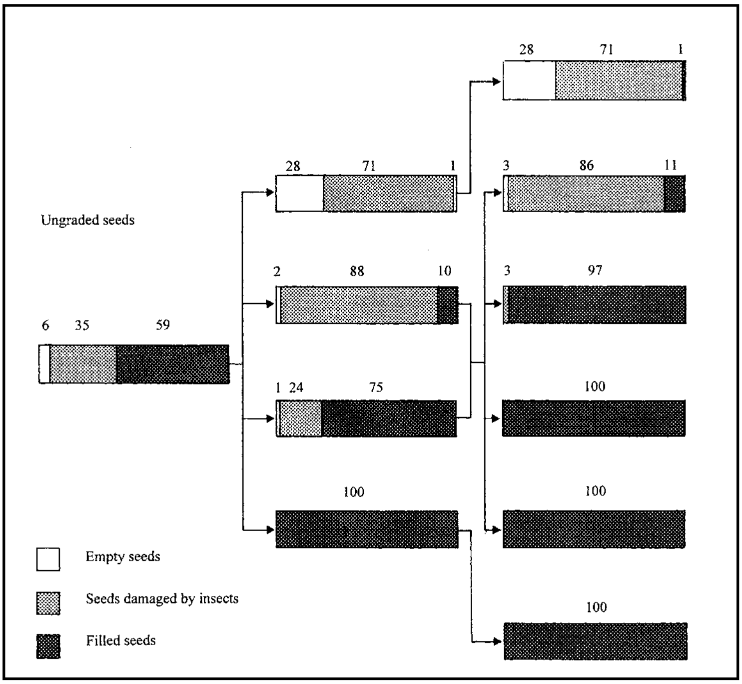
Cleaning is a separation process. Some cleaning procedures separate the seed lot into only two fractions, one containing the seed and one containing inert matter to be discharged. Other methods may separate the seed lot into several fractions with various purities. Intermediate fractions typically contain 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 gravity. 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. And 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 a possibly reduced price for the seeds.

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 in the other. Mechanical cleaning is discussed under the individual cleaning procedures below, and some machines are presented in appendix A6.1.

Type of cleaning machine must be chosen according to seed type and adjusted appropriately to each seed lot in order to operate efficiently.

Figure 6.9.
Example of cleaning effect on purity of a seed lot. After the first cleaning the seed lot is separated into four fractions of increasing purity. One part consists of 100% pure seed, another part consists of almost pure debris and damaged + infested seed. The two intermediate fractions consist of a mixture of seed and impurities. These fractions need a further cleaning with new adjustment of the same procedure (e.g. different air speed during winnowing) or separation by another method (specific gravity, indented cylinder etc.).



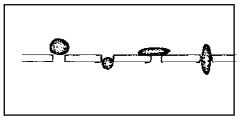
If the clean-seed fraction still contains too much debris, or the debris too much seed after the first cleaning, the machine should be adjusted and cleaning repeated. Some seed lots may be efficiently cleaned by one cleaning method e.g. sieving or winnowing. If more than one method must be applied, the order is chosen so that as much debris as possible is removed by the first methods. This is in order to reduce bulk during subsequent processes. An example of a sequence of cleaning is sieving winnowing flotation. Appendix A6.2 shows examples of the sequence of mechanical cleaning of a seed lot.

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 2, 3 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. Often the initial separation makes more complicated procedures like flotation, IDS or PREVAC (see below) redundant.

6.6.1 Sieving

Applicability. Removal of large and small objects from the seed lot. Also used during fruit cleaning (pre-cleaning) and for seed grading. High purity can be achieved for relatively spherical seeds and objects. Less effective for flat or winged seeds.

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



Method. 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. Small seed lots of small seeded species like eucalypts are efficiently cleaned using 20 cm diameter laboratory sieves. Larger sieves are used for larger seeds and seed lots (ATSC 1995). The hole size and shape depend on seed size and shape and type of impurities. In Australia the mesh sizes employed vary from 1 to 4 mm for eucalypts and 3 to 12 mm for acacias (ATSC 1995).

A screening series consist of at least two sieves (fig. 6.10):

1. A sieve with openings larger than the seeds typically removes large material like fruit at twig fragments. The holes are adjusted to allowing the largest seeds to pass by their narrowest diameter. Shaking or sliding the seeds over the screens will make them pass.
2. A sieve with openings smaller than the seed retains the seeds while smaller debris passes through. The holes are adjusted to retain the smallest viable seeds.

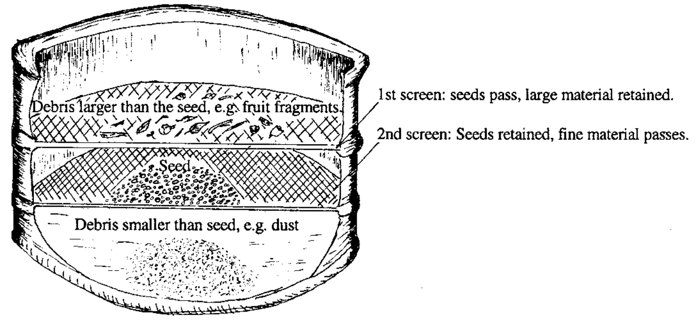


Figure 6.10. Cleaning of eucalypt seeds by sieving. Opening size: upper screen e.g. 2.5 mm for Eucalyptus globulus; 1.5 mm for E. obliqua, E. delegatensis and E. sieberi; lower screen: 0.5-0.7 mm as appropriate. Redrawn from For. Com. Tasmania, 1994.

Sometimes several screens with gradually decreasing mesh or hole sizes may be used and the seeds graded according to size. The grading may be maintained during subsequent cleaning. In some instances small seeds are deliberately discharged (see section 6.7).

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. Fig. 6.11 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) (Karfalt 1998). The appropriate hole size is found by the following method:

1. Place a stack of screens with the correct hole type on top of each other, with the largest opening on top and then decreasing to the smallest opening at the bottom.
2. Pour the seed sample in the upper screen and shake gently to let seed and debris pass holes larger than their diameter.
3. Disassemble the stack of screens and examine the best separation. Choose the appropriate screen size(s).

With small difference in opening sizes more than one of the middle screens may contain both seed and debris. Here one must decide the degree of acceptable contamination. If high purity is required, using several screens (grading) may clean the seed lot. Round or spherical seeds can often be cleaned to high purity by sifting alone, while the method is less effective for flat or winged seeds.

Meshes or holes will inevitably be blocked (blinded) by intermediate size fractions during operation i.e. seeds and particles too large to pass the opening and too small to be left above the screen. The screens must therefore be regularly cleaned, e.g. by brushing. In mechanical cleaners, screens may be kept clean and blockages of intermediate material prevented during operation by brushing or by placing round rubber balls on the screens. The balls tend to push down or break material getting stuck in the holes. A more efficient method is to place the rubber balls on wire-mesh screens with large mesh size under the functional screens. The vibrating movements during operation will make the balls jump up against the screen above and push up material which blocks the holes (see fig 6.12).

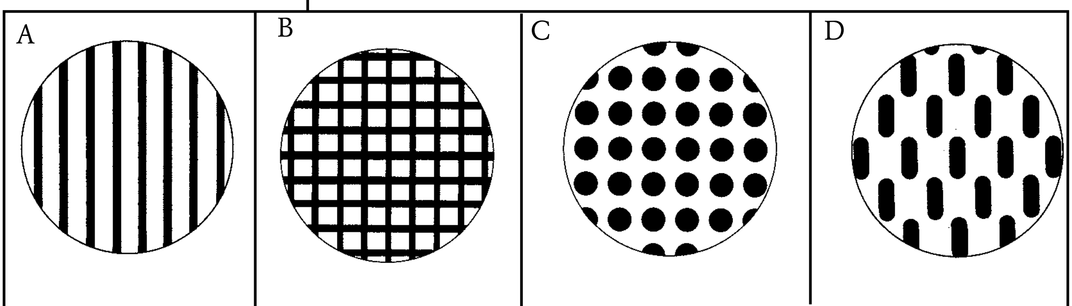


Figure 6.11. Screens with different hole types used for different seed types in mechanical seed cleaners. A) Grid type used mainly for pre-cleaning, e.g. branchlets and leaves from large seed. B) Wire mesh type; this screen has a relatively large opening area compared to metal sheets (C-D) and thus faster in use 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).

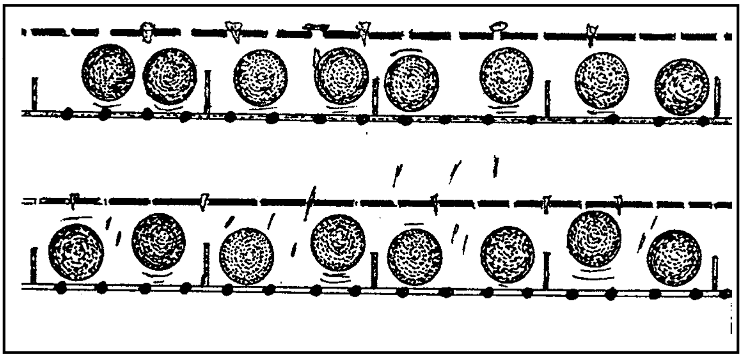


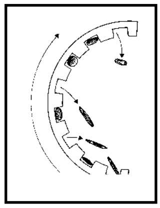
Figure 6.12.
Cleaning of blocked holes during mechanical sifting. Wire mesh screens with rubber balls are placed under the functional screens. During operation the balls jump and push up any material being stuck in the holes.

6.6.2 Indented cylinder cleaning

Applicability. Separation of seeds and debris according to size or length.

Especially useful for separating twig pieces, pine needles and the like from spherical seeds. Not useful for large seed and seed with large wings or hairs.

Physical background. Sorting according to size is based on the same principle as sieving. Sorting according to length is based on the difference in gravity point of short and long seeds. When indented in a short pocket in horizontal position, short seeds have their gravity point within the pocket and remain there, while long seeds with gravity point outside the dent fall out.



Method. The indented cylinder consists of a cylinder with numerous indentions in its inner surface, revolving round a sloping axle. Above the axle along its length is a fixed sloping trough (fig. 6.13B). 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 the inset.

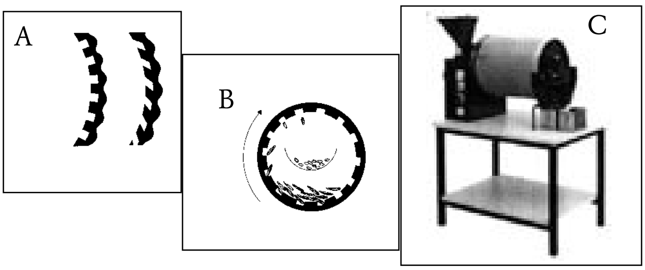


Figure 6.13.
Cleaning by an indented cylinder. A. Different types of indents. Cylinders with asymmetrical indents (right) have proven more effective in separation than the type with symmetrical holes (left). B. Separation of short and long seeds. Short seeds are carried upwards into the trough, long seeds fall back into the cylinder. C. An example of a laboratory indented cylinder.

When used for size separation, a cylinder with pocket size that will allow only small size seeds to fit into the pockets is used. Large seeds, which do not fit into the pockets, remain in the cylinder and move downward to the lower end. Small seeds are carried upwards and fall into the trough.

When used for separation according to length, both short and long objects initially fit into the pockets and are carried upwards. However, long objects like twigs or straw, fall out before they reach the trough and thus remain in the cylinder (Thomson 1979).

Cylinders with different pocket sizes are available and are easy to change according to seed size. The flow through the cleaner is adjusted by adjusting the slope of the cylinder.

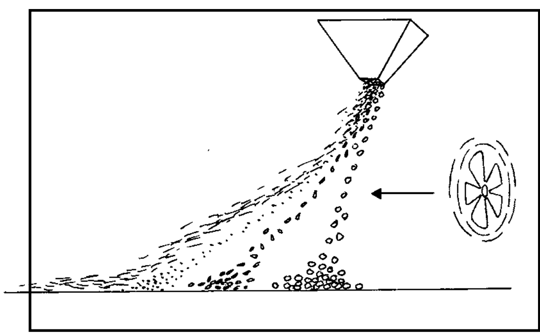
6.6.3 Winnowing and blowing

Applicability. Removal of dust, chaff, wings or other light material from seed lots. Less effective for light winged seed.

Physical background. Blowing and winnowing separate material according to different gravity (weight/volume) and surface/volume ratio. An object with a large gravity (e.g. a stone) or a 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 a smaller gravity (e.g. wood) or large surface/volume ratio (e.g. a leaf).

Method. In its simplest form of winnowing, seeds are held in large flat baskets. The seeds to be cleaned are thrown up into the air, and the wind will then blow away light matter like dust, wings and leaf fragments, while the heavier seeds will 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.

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 stationary fans or propellers. The strength of the air current is adjusted according to seed type and debris. To work effectively, the seed must be fully exposed to the air current. There are two variants. Either the seeds pass vertically through the air current (fig 6.14 A) or shaking them on an undulating surface over which the air current runs (fig 6.14 B) elevates the seeds. 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 intermediate fraction contains a mixture of light seed and debris with decreasing purity away from the air source. This fraction is sometimes sorted by cleaning machines into several sub-fractions that are subsequently re-cleaned by winnowing or other methods.



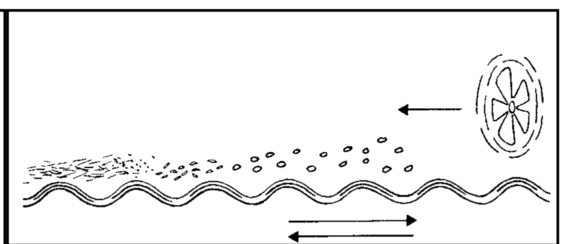
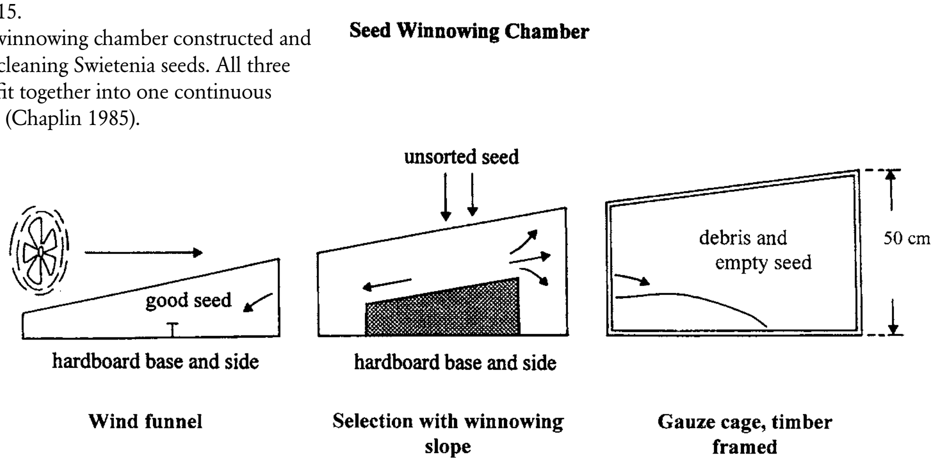


Figure 6.14. Two applications of the winnowing system. A. The seed lot is displaced horizontally by the air current during fall. B. The seed lot is exposed to the airflow by elevating them over the surface by shaking.

A simple winnowing chamber, primarily designed for cleaning seeds of Swietenia macrophylla but with wide applicability, is shown in fig. 6.15. The chamber consists of 1) a wind funnel from where an air current is created by a fan, 2) a central section with a formica top sloping against the air current, and 3) a gauze cage where light debris is collected. The uncleaned seeds are fed from the top above the central slope and pass through the air current. Light matter is blown into the gauze cage, the seeds fall down on the slope and roll or slide down. Slope, height of drop and strength of air current can be adjusted according to seed type (Chaplin 1985).

Figure 6.15.
Simple winnowing chamber constructed and used for cleaning Swietenia seeds. All three sections fit together into one continuous chamber. (Chaplin 1985).



The physical principle of air current displacement is also used in seed blowers, which are mainly used for small seed types such as eucalypts and casuarinas. The seed lot to be cleaned is placed in a vertical cylinder connected to an electrical powered air current at the bottom. 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. The cylinder can be emptied in sections so that the mid section, which typically contains a mixture of seed and debris, can be re-cleaned.

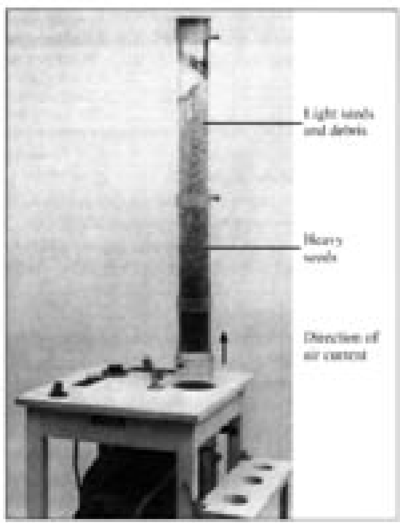


Figure 6.16.
Separation by blowing. South Dakota Seed Blower.

6.6.4 Specific-gravity separators

Applicability. Separation of seeds and objects differing in weight, density and surface characteristic. High precision with consequent high purity can be achieved for many species.

Physical background. The separation is, as for 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.

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

1. Oscillating table. The separator consists of a slightly inclined table with zigzag partitions along its length (see fig. 6.17). 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 by 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 type. As the seeds move on the deck during operation they are also influenced by their surface structure. A surface with a high friction is slowed down during movement and follows the stream of heavy seeds.

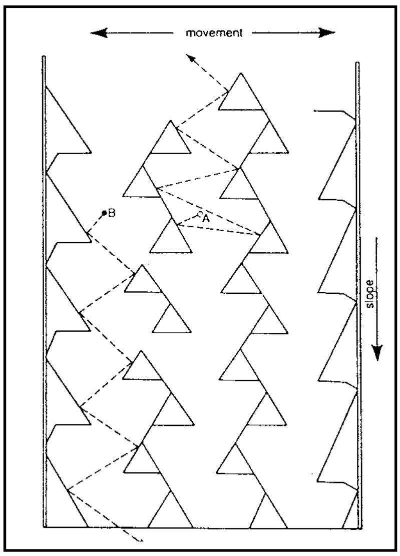


Figure 6.17.
Principle of the oscillating table: a light object (A) is hit by the zigzag movement of the partitions of the oscillating table and moves upwards. A heavy object (B) is hit by the first partition but because of the gravity force it fails to be hit by the next and consequently moves downwards.

2. Pneumatic table separator or specific gravity table. The separator consists of a slightly inclined table with a porous surface, e.g. a woven linen cloth, connected to a compressed air source (fig. 6.18). 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.

Pressure of the air stream, inclination of the table (in two directions), and surface of the deck can be adjusted to seed type. Size of the deck varies in different models, the smaller with maximum length of some 25 cm, the larger models about 125 cm.

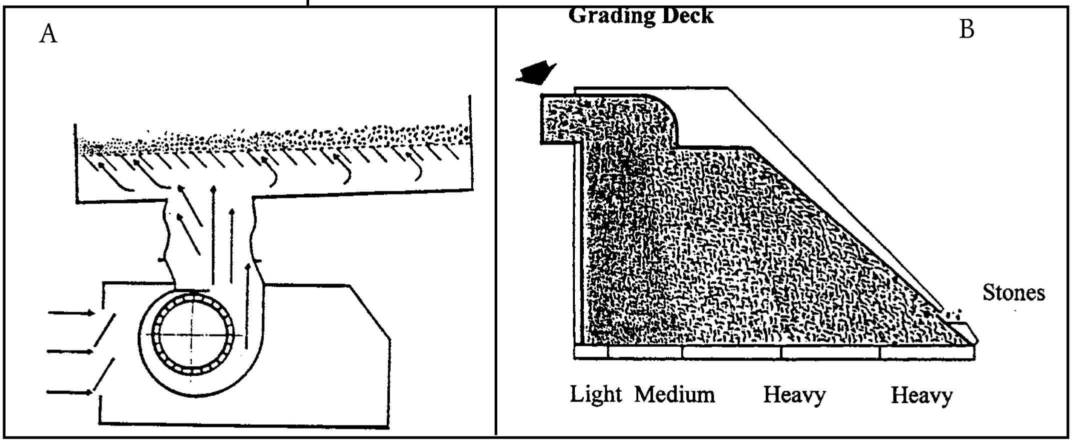


Figure 6.18. Principle of separation by the pneumatic table separator. A. Transverse section of the separator showing how the seeds 'float on an air cushion' with the heavier seeds under the lighter seeds. B. The separator seed from above. The seed is fed onto the table at the black arrow. Vibration of the inclined table makes the heavier seeds move to one end of the table and the lighter seeds or debris to the other (from Jensen 1987).

6.6.5 Friction cleaning

Applicability. 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.

Physical background. Shape and surface structure make material slide differently down a slope with high friction material. An object with a high surface friction (e.g. a leaf) can stay on a steep slope while an object with low friction (e.g. smooth paper) will slide down. Further, an object with a low gravity point may stay on the same slope while an object with a high gravity point will roll down. Since spherical objects have both a small friction and a high gravity point, they will roll down a slope with a relatively small angle.

Method. 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 (fig. 6.19). 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 (fig. 6.20). 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 gravity point, 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).

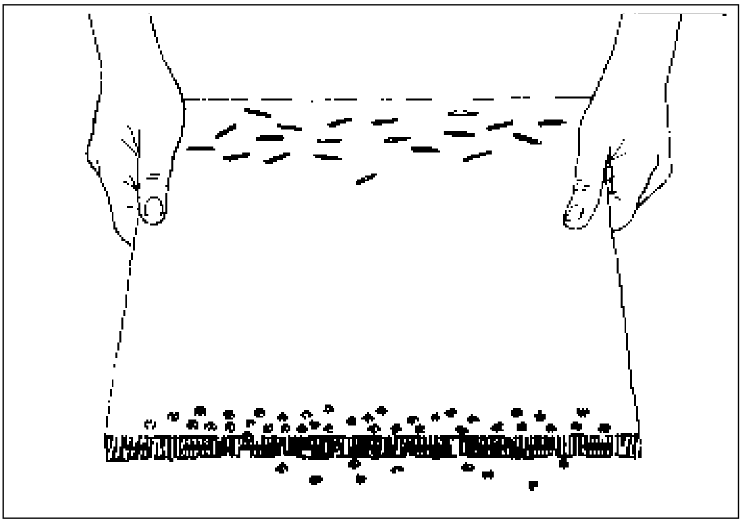


Figure 6.19.
Methods of separating seed according to surface friction and gravity points. Sloping cloth frame; round or smooth seeds roll or slide down the frame while flat and rough seeds and debris remain on the top part of the frame.

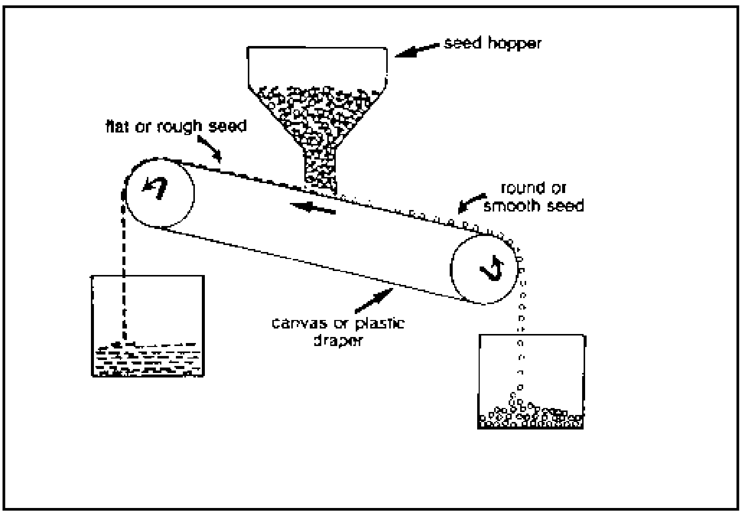


Figure 6.20.
The rotating belt carries small flat or rough particles and seeds upwards, while round or smooth seeds and heavy particles roll down

6.6.6 Flotation

Applicability. Separation of mature viable seeds from chaff, empty seed, filled dead seed, immature or insect-damaged seed (grading, see section 6.7) or other particles with a specific gravity smaller than that of seeds. 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 gravity difference between sound seed and inert matter is very small.

Physical background. An object placed in a liquid medium will float if its specific gravity or density (weight/volume) is smaller than that of the liquid, and sink if it has a higher specific gravity than the liquid. Most seeds have a density slightly below 1.0 when dry, while their gravity is slightly above 1.0 when imbibed. That implies that they will tend to float in water (specific gravity = 1) when dry and sink when imbibed. The IDS and PREVAC methods below use the fact that sound seed absorbs and desorbs water at a different rate than dead filled seed and damaged seed.

Method. Two methods are described by Simak (1973), viz. density method and absorption method.

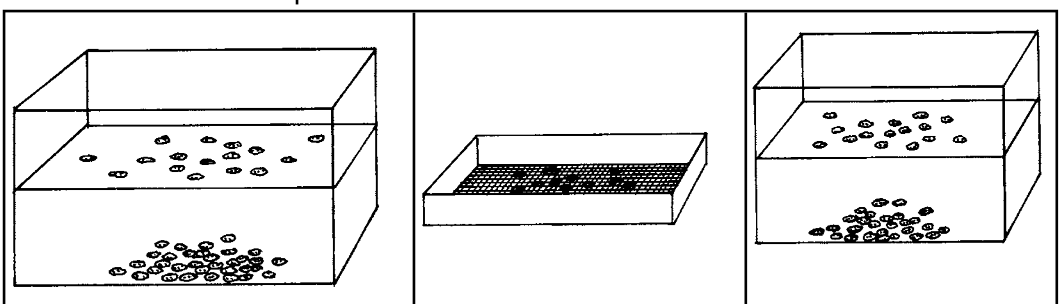
1. Density method. A liquid with a density or specific gravity between those of full and empty seeds (usually below 1.0) is used. Full seeds will sink and empty seeds and light debris float. To work effectively the specific gravity of the flotation medium must be adjusted to a level between the light and heavy material. Table 6.3 lists a number of liquids that have been used for separation by liquid flotation. 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. In separation of filled and unfilled seed of Araucaria cunninghamii a mixture of 95% ethanol and n-pentane in different proportions were used. It was shown that the density of filled and unfilled seed varied with clones, and the density of the flotation medium thus had to be adjusted accordingly (Haines and Gould 1983).

   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.

Table 6.3. Specific gravity of some liquids used for separation by flotation.

Medium	Specific gravity
Pure water	1.0
Abs. alcohol (ethanol)	0.791
95% alcohol (ethanol)	0.806
50% ethanol	0.90
Diethyl ether	0.714
Petroleum ether	0.657
n-penthane	0.626
Mixture 95% ethanol and n-pentane, 3:1	0.76
Mixture 95% ethanol and n-pentane, 12:13	0.71
Linseed oil	0.93

2. Absorption method. Seeds to be sorted are poured into water (specific gravity 1.0). 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.



1. Imbibition and flotation (2 min. - 2 hours). Light debris float and are skimmed off. All seeds absorb water and sink	2. Drying (2 min. - 2 hours). Damaged or infected seeds dry fast, sound seeds lose water slowly.	3. Flotation (short). Sound seeds sink, damaged or infected seeds float and are skimmed off.

Figure 6.21. Principle and procedure of separation by flotation in water by the IDS method.

The absorption method has been further developed into two practical methods, the IDS and PREVAC methods. 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. In 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 days of incubation the seeds are partially dried, and separated by flotation (fig. 6.21). 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). A method used to separate seeds with mechanical damage from sound seeds. Dry (unimbibed) seeds are exposed to low pressure (vacuum) for 1 to 20 minutes 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 that undamaged seed. During subsequent flotation, damaged seeds tend to sink while undamaged seeds tend to float (Bergsten and Wirklund 1987). (Notice that the flotation principle here is the opposite of the one described above in which sound seeds sink).

In Australia a method using a combination of the density method and the absorption method is used for the separation of live seeds of Eucalyptus pilularis from chaff and dead seeds. The seeds are initially pre-imbibed in water for 2-4 days, then separated in a sugar solution (ATSC 1996).

6.7 Seed Grading

While the objective of seed cleaning is to improve purity by eliminating non-seed material and foreign seed from the seed lot, the purpose of grading is to improve the average physiological quality of the seed lot by removing seed of the same species with low quality. Such seed may be empty seed, immature seed, damaged or dead seed or seed developed after self-fertilization. In the latter case the removal also serves to improve the genetic quality of the seed lot. Sometimes a larger fraction of small yet viable seed is deliberately removed from the seed lot based on an assumed correlation between seed size and vigour.

A positive correlation between seed size and seedling size/vigour has been documented for several species. Often large seeds tend to germinate faster and produce larger and more vigorous seedlings than small seeds of the same species. The difference is usually pronounced during the early stages of seedling development but tends to become smaller and may disappear after one or more growth seasons. (Dunlap and Barnett 1984, Fowells 1953, Griffin 1972, Sorensen and Campbell 1993). From a silvicultural point of view, swift and uniform germination and seedling establishment is obviously an immediate advantage, albeit not necessarily correlated with ultimate yield.

Grading according to size can be useful to assure a more uniform germination speed and seedling growth within each grading class. A uniform seed size facilitates sowing with sowing machines and a uniform germination and seedling growth rate will imply fewer cullings (Creemer 1990). Grading, with elimination of the lightest seeds, may influence the genetic composition of the seed lot by selectively removing seeds of families with relatively small seeds, a problem discussed more thoroughly in chapter 12.

Seed grading may in practice be an extension of the seed cleaning process because the small and light seeds are removed together with chaff and other impurities. Methods of grading must, however, be adjusted much more precisely since the physical difference of seeds within a species is likely to be much less than between seeds of different species or seeds and extraneous matter (see flotation, section 6.6.6).

6.8 Adjusting Moisture Content for Storage

After having obtained clean pure seed the final processing procedure is to adjust moisture content for seed that is to be stored for any length of time. The appropriate moisture content varies with species and potential storage period. Orthodox seed, which includes most dry-zone species plus most humid zone pioneers (see chapter 2.7), has no lower moisture content tolerance level. A moisture content of 6-8% normally assures safe storage; lower moisture content is only appropriate for long term storage at very low temperature. Recalcitrant seed, which prevails among humid zone climax forest species, does not tolerate much desiccation and must be stored with a high moisture content for the shortest possible time. A large intermediate group (semi-orthodox, semi-recalcitrant or 'intermediate' seeds) shows varying levels of tolerance. While orthodox seed is either further dried or maintained at the moisture level achieved during processing, recalcitrant and intermediate seed may need re-moistening for safe storage. The moisture content for these species is adjusted to the minimum for safe storage. The actual moisture content of the seed lot is measured before storage either by a calibrated moisture meter (appendix A5.3) or by the ISTA oven method (section 11.6.3).

6.8.1 Orthodox seed

Most orthodox seed can be stored safely for at least 1-2 years at a moisture content of 8-10% or below. Potential storage period is prolonged by cold storage as will be outlined in chapter 8. For long term storage at sub-zero temperatures a moisture content of 2-4% is desirable. The principles of seed drying are presented in appendix A.5.2. Drying may be carried out by natural sun drying or artificial heating with a dry air current, which is usually supplied by electrical appliances. The relation between moisture content and heat should be recalled: moist seed is less tolerant to heat than dry seed. If the initial moisture content is high, e.g. after moist extraction or cleaning, care should be observed not to overheat seed during the initial drying stage. The following drying temperatures may be suggested:

1. Air temperature 30-35°C until moisture content has lowered to 10-12%.
2. Air temperature 35-45°C until moisture content has lowered to 5-10%.

3. Air temperature 45-55°C until moisture content has lowered to 3-5%.

Once the seeds have been dried to an appropriate storage moisture content, they should be stored in air-tight containers as soon as possible to avoid re-gain of moisture from the air. The rate of re-absorption depends on species. In Nepal, Napier and Robbins (1988) report that Alnus nepalensis under humid conditions may re-absorb moisture within hours after drying.

6.8.2 Recalcitrant and intermediate seed

Although recalcitrant seed has high water content when shed, most species undergo some kind of maturation drying (see further chapter 8). The lowest safe moisture content varies with species and specific information should be consulted. For some recalcitrant seeds the rate of moisture reduction has shown influence on subsequent storability. Triplochiton scleroxylon, whose seed normally lose viability in a matter of weeks, was shown to tolerate drying down to 8% m.c. provided the moisture content was lowered by about 1% per hour. The seeds could then be stored at low temperature and maintained viability for more than a year (Bowen *et al.* 1977). Thailand provenances of neem (*Azadirachta indica*) maintained a high viability (≈ 60%) after 6 weeks of storage when the seeds were sundried for 2-3 days. Both shorter (1 day) and longer (7 days) duration of drying gave inferior germination. No major differences in storability were found after 8 weeks' storage following alternative drying methods and rates (Chaisurisri *et al.* 1986). Thompset (1982) found, however, that the rate of drying was of no importance for the storage behaviour of *Araucaria hunsteinii*. The effect of drying rate on most other recalcitrant seeds still needs to be revealed.

Sensitive seeds may suffer from accidental desiccation damage caused by processing. Such damage cannot be restored by re-moistening, but desiccation may be minimised by storing the seeds with a safe moisture content and in an environment where further desiccation is avoided. Re-moistening is technically the opposite of drying. For recalcitrant seed it is, however, complicated because a balance must be maintained where moisture content increases to the desired level without initiating imbibition and germination. Re-moistening by absorption from humid air may be easier to control than submerging the seeds in water. Regarding safe moisture content for various species, reference is made to table 8.2.

6.9 Potential Seed Damage during Processing

Seed processing aims to achieve a balance between maximising effectivity (extraction, cleaning, protection against deterioration) and damage to the seeds. In practice, processing always implies a risk of damage or injury to some seeds. Damage may occur in various ways:

1. **Mechanical damage**. Usually on the seed-coats but occasionally on the 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).

2. **Heat damage**. Often occurring by exposure to 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, and recalcitrant seeds are, accordingly, sensitive to heat damage.

3. **Chemical damage**. Sometimes occurring during separation by flotation in organic liquids. Other potential sources are fungicides.

4. **Water**. Prolonged submersion in water, e.g. to soften the fruit pulp may hamper respiration of the seeds. Prolonged soaking may also cause imbibition and initiate germination in seeds with no dormancy.

The severity of the damage depends on extraction / handling procedure and of seed type:

1. The more fragile the seed, the more sensitive it is to damage. Seeds with thin seed-coats or large cotyledons without or with little enclosing endosperm are easily damaged by some processing methods.

2. The more frantic the process, the higher the potential damage. Threshing and beating e.g. of indehiscent pods imply a potential risk of breaking the embryo. Especially sensitive is the attachment site of the cotyledons to the embryonic axis (Moore 1972). Mild impact to seed-coats can have a beneficial influence on germination by breaking physical dormancy (see chapter 9).

Studies on the effect of seed processing on seed quality have mainly concentrated on conifers. In comparison with other species, conifers require quite a lot of handling and processing in order to extract the seeds, and their seeds are often subsequently dewinged to ease handling. At the same time seeds of many conifers are fragile and easily damaged by handling. Handling damage while the seeds were still enclosed in the cones has been reported for *Abies* spp. Throwing sacks of cones to the ground during collection was sufficient to cause quality reduction (Edwards 1981).

Damage during dewinging may occur when seeds are tumbled e.g. together with debris. Heavy damage has been encountered in seeds of *Abies lasiocarpa* where up to 50% of the seeds was lost. Excessive dewinging resulted in dull dusty seed-coats, susceptible to mould and resulting in weak seedlings (Edwards 1981).

Temperature damage of conifer seeds during extraction in kilns has been widely reported. Most sensitive are immature and moist seeds, and temperature damage is accordingly most likely to occur during the early phases. Potential damage also depends on length of exposure.

Wang *et al.* (1992) found a substantial loss of viability of *Pinus contorta* var. latifolia seeds by exposing the cones to a scorching temperature of 220°C for more than 1.5 min. Shorter exposure did not impair viability, possibly because the temperature inside the seed did not rise to a fatal level for the embryo.

A few investigations suggest that seed damage may occur during chemical treatment. Fumigation with carbon disulphide or hydrocyanic acid for killing *Megastigmus* spp. in conifers affected viability (Sweeney *et al.* 1991). Some alcohols used for flotation (section 6.6.6) had a negative effect on the viability of *Pinus* seeds; others caused no loss in viability (Hodgson 1977).

There is little documentation on mechanical damage to forest seed during processing, but some parallels may be drawn from experience from agricultural seeds. In maize (*Zea mays* L.) various degrees of damage on seed-coat, endosperm and embryo could be detected in 89% of the seeds after processing (Jahufer and Borovoi 1992). The injuries affected germination, seedling development, susceptibility to diseases, plant growth and development and grain yield. The germination rate and seedling quality was influenced by the location of damage, the embryo and especially the central part being the more sensitive.

Minor damage to seeds during processing may not immediately affect viability but may cause reduced seedling vigour and misshapen seedlings (More 1972). Damage also affects storage potential since injured or deeply bruised areas may serve as centres for infection (Bewley and Black 1994, Brandenburg 1983, More 1972, Veira *et al.* 1994). This may partly be caused by an accelerated progressive deterioration (see chapter 8) or interaction with other deteriorating factors, e.g. increased susceptibility to fungal infection through cracks in the seed-coat. Injuries to or near delicate parts of the embryo are prone to both primary and secondary deterioration.

While heat damage is most likely to affect moist seed, dry seed seems more susceptible to mechanical damage (More 1972). Therefore it must be advised that seeds should only be moderately dried before mechanical treatment e.g. extraction, dewinging and cleaning.

6.10 Safety Precautions during Processing

Like seed collection, processing implies both general and specific safety hazards. Processing staff should be familiar with these potential risks and observe appropriate precautions.

1. 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.

2. **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. Some species, e.g. *acacias*, are known to release especially large amount of dust when threshed.

Because dust is dry, it causes a general irritation of eyes, nose, and skin with resulting itchiness, coughing and sneezing. For most people this is merely annoying, but for some people some dust elements cause 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.

Softening the fruit flesh of sugar palm (*Arenga pinnata*) by soaking prior to depulping requires caution. Decomposing fruits develop a fluid causing intense itching and burning whenever it comes into contact with the skin. Also contact with the seed-coat can cause skin irritation (Masano 1990). Processing of seeds of *Platanus* spp. and several species of the family Boraginaceae are known to give similar skin irritations. Rubber gloves must be used when handling these fruits.

3. **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.

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

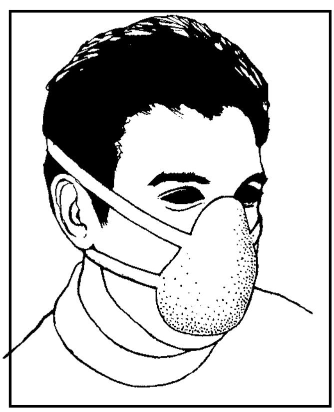


Figure 6.22.
Disposable dust mask covering mouth and nose, used during fruit and seed processing where excessive dust is released.

6.11 Maintaining Identity during Processing

During processing the fruits and later the seeds pass through a number of processes, they are unloaded and loaded into different containers and processing equipment, and often handled by a number of people. The risk of losing or accidentally mixing labels are obviously high, especially when handling a number of minor samples of the same species, e.g. single tree collections or provenance collections. A system must be created to minimise the risk of losing seed identity. Handling of labels is, in many cases, as important as handling of the seed itself. Simple routine procedures are recommended. If some members of the staff are not able to read the labels, they should still be able to maintain the routines. Some points are summarised below:

- 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, 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 discharged.
- 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,...
- Discharged 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.

A second point in maintaining identity relates to the risk of physically contaminating the seed lots. If the seeds are to be used for trials, contamination may completely distort the results. It is rarely possible to clean a seed lot for seeds of the same species, and separation of seeds of some species with very similar seeds may also be impossible. Therefore, contamination is often irreversible.

The chances of contamination during seed processing are many. Light seeds may blow from one seed lot to another; perforations in containers or trays may cause seeds to slip from one container or tray to the next if stacked; seed may be stuck in storage containers or processing equipment, especially tiny seeds like eucalypts, Anthocephalus or casuarinas. Hygiene 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.

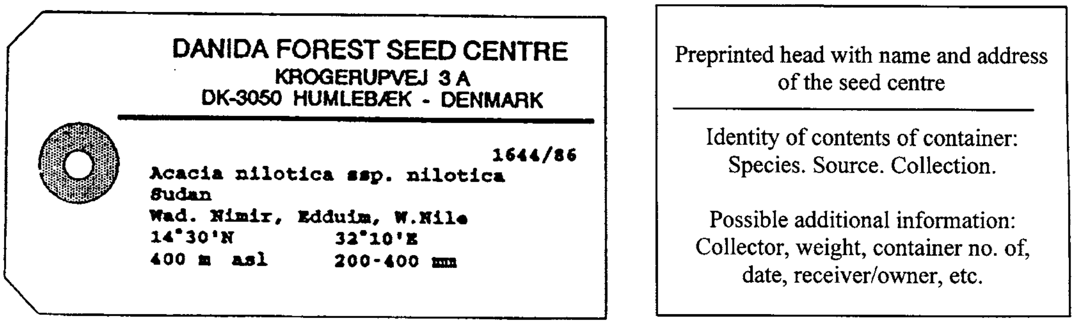


Figure 6.23. Labels used for seed lots. Two identical labels are used, one is tied or stuck outside the bag or container, the other put together with the fruits or seeds inside the bag or container.

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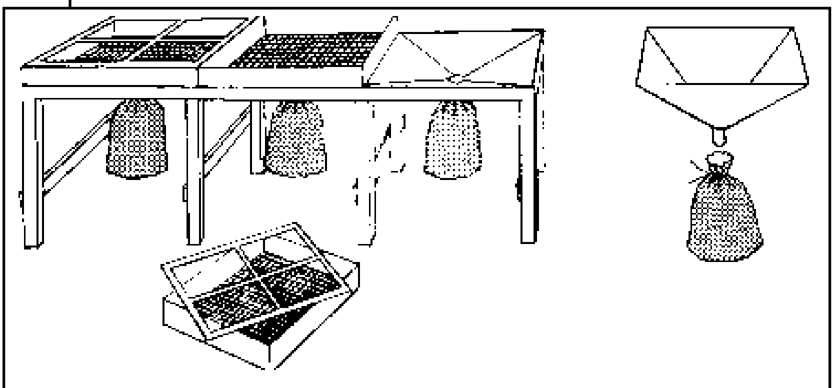
Appendix A6.1. Equipment for seed processing

a. Extraction trays for small dehiscent fruits, or small lots of larger dehiscent fruits

The extraction unit consists of a firm wooden stand, 90-100 cm high, 80-100 cm wide, length variable. Extraction of the fruits takes place on wooden trays, which are placed on top of the stand. Each tray consists of a wooden frame for the sides and wire mesh at the bottom. Height of the wooden frame and mesh size depend on fruit and seed size. The wire mesh should allow seed to pass but retain the fruits. To collect the seeds, a rectangular funnel made of galvanised zinc sheet or the like and the same size as the trays, is placed under each tray. The funnel has a tube outlet in the bottom, on which a small cotton bag for seed collection can be tied. The zinc sheets and tube of the funnel must be soldered together. As an alternative to the zinc funnel, each tray may be provided with a collection device tightly mounted on the tray bottom.

The dry fruits are spread on the wire mesh in a thin layer and turned regularly to assure uniform drying. To speed up extraction each tray may be provided with a framed polythene cover.

Figure A6.1. Extraction trays and stand. Redrawn from Granhof 1984.



b. Tumblers

The principle of tumbling finds wide application in seed handling, e.g. for extraction, de-winging, polishing and pretreatment of seeds. Cement mixers are used for several of these procedures. Fruits or seeds are here tumbled together with abrasion material like sand or gravel, wooden blocks and sometimes water.

Some tumblers are constructed specially for extraction and pre-cleaning of seeds. They consist of a vertical drum with circular or square cross section mounted on an axis (fig. A6.2). The side of the drum is made of perforated material, e.g. wire mesh which retains the fruits and other large fragments, allowing seed and small debris to pass and be collected on a sheet under the drum. As the drum revolves, the fruits either slide or roll, or they are carried towards the top position of the drum and fall down on the lower side. Large diameter drums have a larger falling distance and consequently larger mechanical impact when the fruits fall. Maximum impact is achieved when the rotation speed is adjusted so that the fruits fall from the top position. Fast rotation may cause the fruits to adhere to the side due to centrifugal force resulting in ineffective tumbling; slow rotation may allow the fruits to roll and slide down without falling. The latter is avoided in drums with square cross-sections.

Dimension, speed of rotation and duration of tumbling should be adapted to fruit type. Tumbling is stopped when all normal seeds have been released. If the seeds pass through the drum sides, no harm can be done by excessive rotation. However, small fragments are continuously released from the fruits which will unnecessarily contaminate the seed lot when extraction is completed. Cones often contain small and empty seeds at the apical end. These seeds are often retained in the cone after tumbling, but being non-viable they can be ignored.

Tumbling and kiln extraction are combined in the drum kiln, see fig. A6.5

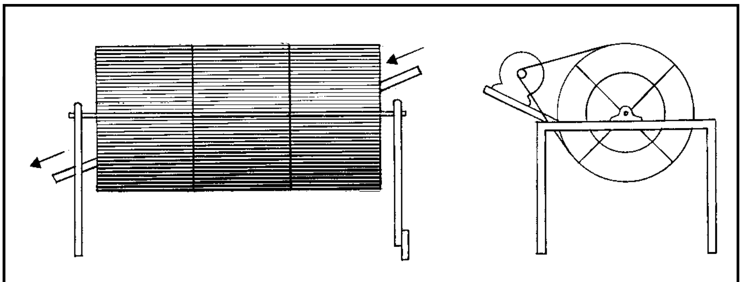


Figure A6.2.
Principle of tumbler used for seed extraction from dry fruits. The legs at the feeding end are adjustable to regulate flow.

Figure A6.3.
Cement mixer used for threshing, depulping, polishing, dewinging and pretreatment of fruit or seed. Fruit or seed material are tumbled together with wooden blocks, sand or gravel, and/or water depending on function. The mixer is provided with an exhaust to remove dust and wings.

c. Drying kilns

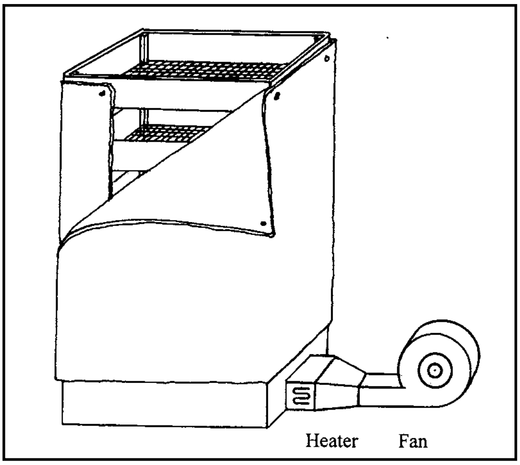
Kilns are used for seed extraction from cones and fruits for which drying at ambient temperature is inadequate. The temperature is raised by artificial heat. Kilns are usually supplied with a ventilation device to remove humidity and provide dry air during operation. In some kiln types extracted seeds are continuously removed from the kilns in order to avoid damage by prolonged exposure to the temperature. Temperature and air humidity can be adjusted in most advanced kilns. Normally drying starts at low temperature, e.g. 35-40°C, which gradually increases as drying progresses.

Several kiln types are available. There are two main types, stationary and rotating. In the former the fruits or cones are placed on trays during seasoning; the seeds are subsequently extracted by tumbling or threshing. In rotating kilns the fruits are moved during the drying process, usually by tumbling. A third form, the horizontal progressive kiln, uses a conveyer to move the fruits through the kiln during operation.

1. Stationary kilns

The stationary kiln consists of stacked trays like the ones used for natural air drying placed over a heat source. As warm air ascends through the trays, the air becomes more humid. The lower trays are thus dried first. Once the cones or fruits in the lower tray have opened, the tray is removed, the other trays are moved down one step and a new tray with fresh cones/fruits is put on top. In this way the fruits are dried slowly and progressively from the top to the bottom. Natural convection will make the air ascend through the trays, but artificial air circulation aided by a fan speeds up the drying process and hence reduces the time the seeds are exposed to high temperature.

Figure A6.4. Simple stationary kiln consisting of stacked trays provided with a heat source and a fan for ventilation.



Stationary kilns have three disadvantages:

1. Drying is not uniform as the fruits or cones closest to the heat source (bottom tray) dry quicker than those away from the heat source (top tray). The trays must therefore be moved as described above, which implies that the kiln must be opened frequently.
2. Seeds from open fruits are not continuously removed and may be prone to heat damage.
3. The kilns only cause the fruits and cones to open while actual extraction has to be done by a subsequent procedure, usually tumbling.

2. Rotating drum kiln

This type of kiln combines the high temperature of the kiln with the mechanical extraction of the tumbler. The drum kiln consists of a horizontal cylinder made of perforated steel plate rotating on a central axis. The drum is provided with a heat source plus a fan for air circulation. A pre-drying box is sometimes placed above the drum using excess heat from the kiln to pre-dry the fruits. Pre-drying reduces the kiln drying time and saves energy. Fruits and cones are filled into the drum through the opening in the cylinder. The drum is filled to approximately half-capacity (depending on expected expansion after drying) and the door is closed. During operation the tumbler rotates at approximately 40 revolutions per minute. The temperature is gradually raised during the process. Seeds are continuously removed from the kiln through perforations in the side of the cylinder and the process is terminated when all sound seeds have been released from the fruits.

The rotating drum kiln has an advantage, as compared to the stationary types, in that extraction can be done in one continuous process, without opening the kiln to move the cones and without a subsequent separate tumbling. Heating and consequently opening of the fruit is uniform during the process and the seeds are removed continuously, thus reducing potential damage by prolonged heat exposure. Extraction may in some instances also be more efficient than in the stationary kiln, viz. in those cases where full expansion of the upper cone scales prevents the release of seeds from the lower cone scales.

A disadvantage/limitation of the rotating drum is that mechanical damage by tumbling may occur before the fruits are fully open. Further, to take advantage of the option of seeds being removed during the process, the perforation must match the seed size. Hence, drum kilns are applicable only to a relatively small number of species.

Figure A6.5.
Rotating drum kiln. Danish Tree Improvement Station.

d. Depulpers

Mechanical depulpers are used for maceration of fleshy fruit covers. Coffee depulpers are the most commonly used depulpers. Depending on fruit type to be depulped they may be used directly (with appropriate adjustment to seed size), or with some modification. Modification usually refers to the surface of the drum, where some fruit types are most easily depulped using a different abrading surface. In most depulpers there is a rough separation of pulp from seeds or stones. Some depulpers are manually operated, others are powered by electricity.

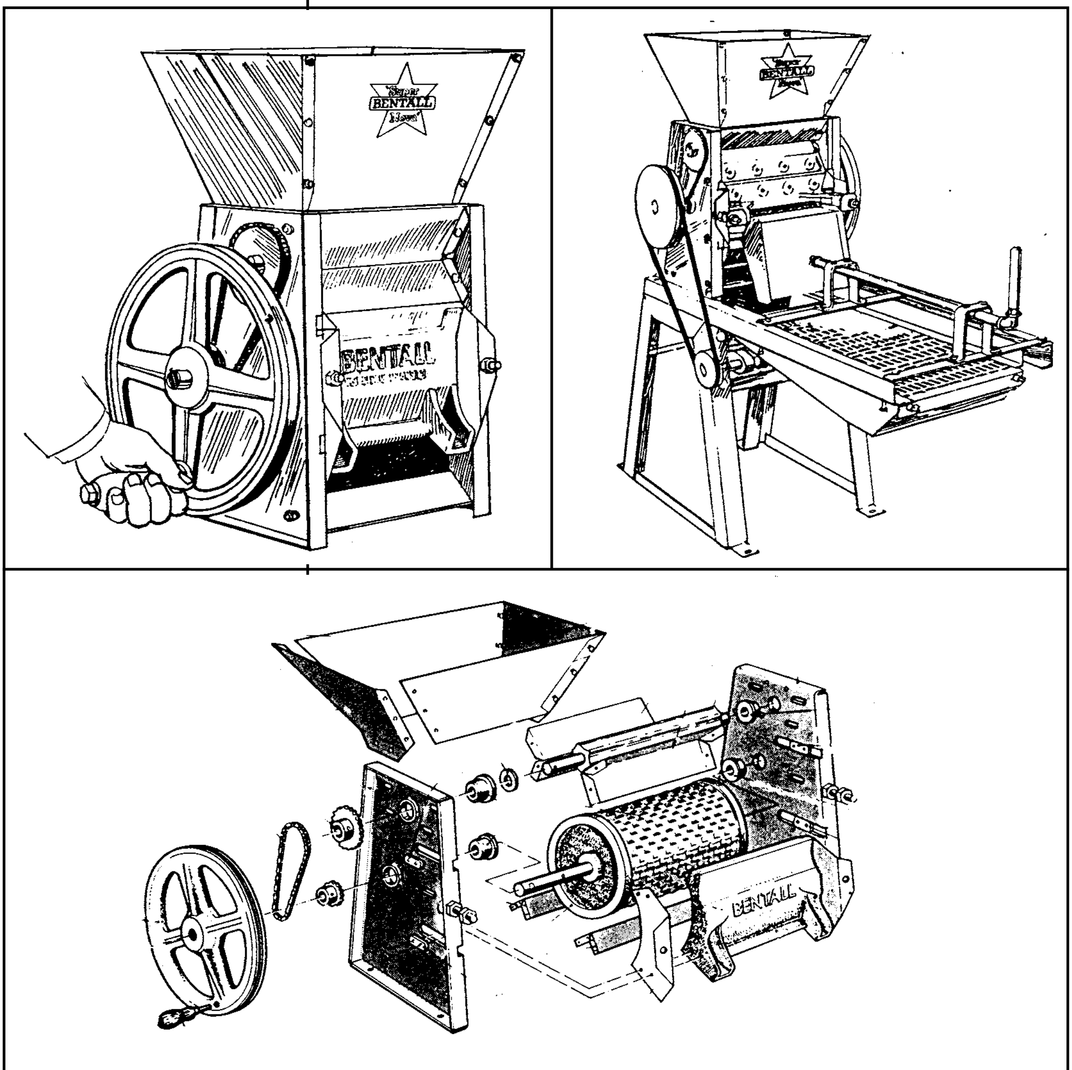


Figure A6.6. Coffee depulper, manual and engine powered version. The mechanical parts of the manual version are shown.

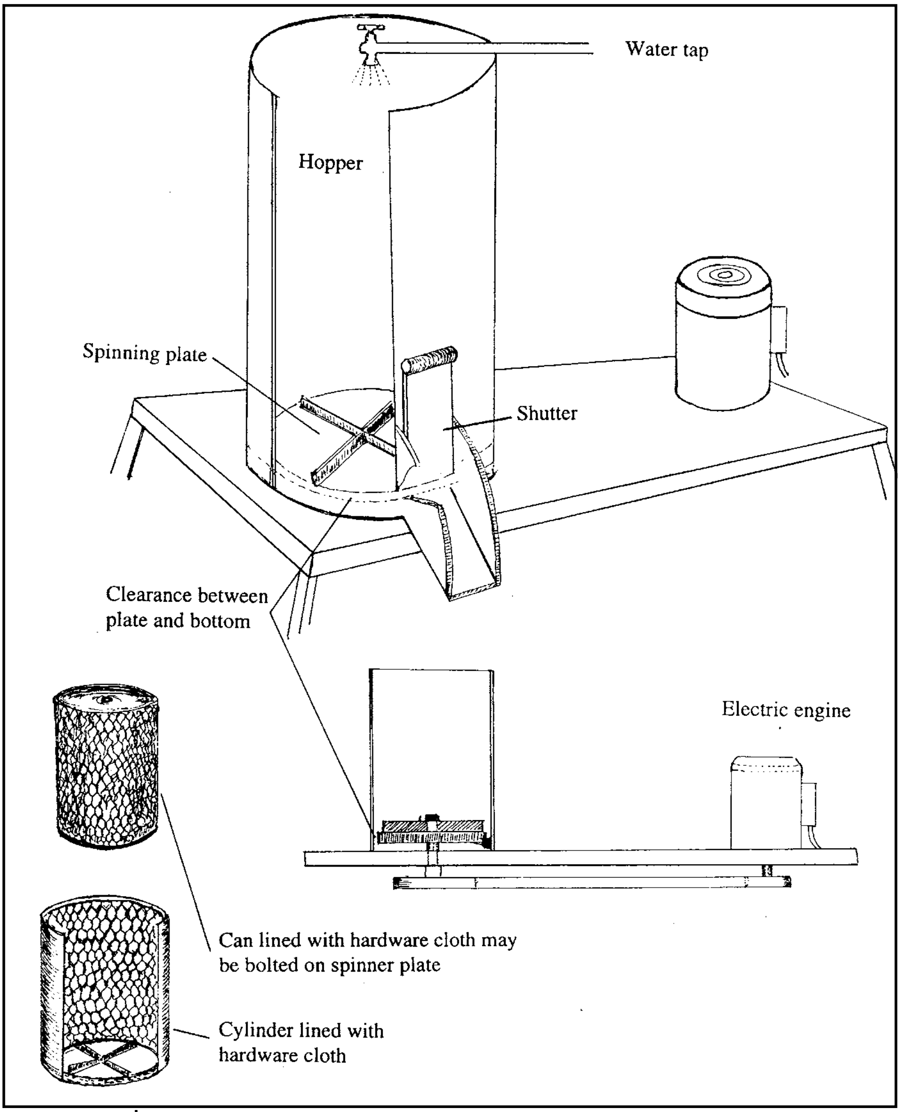
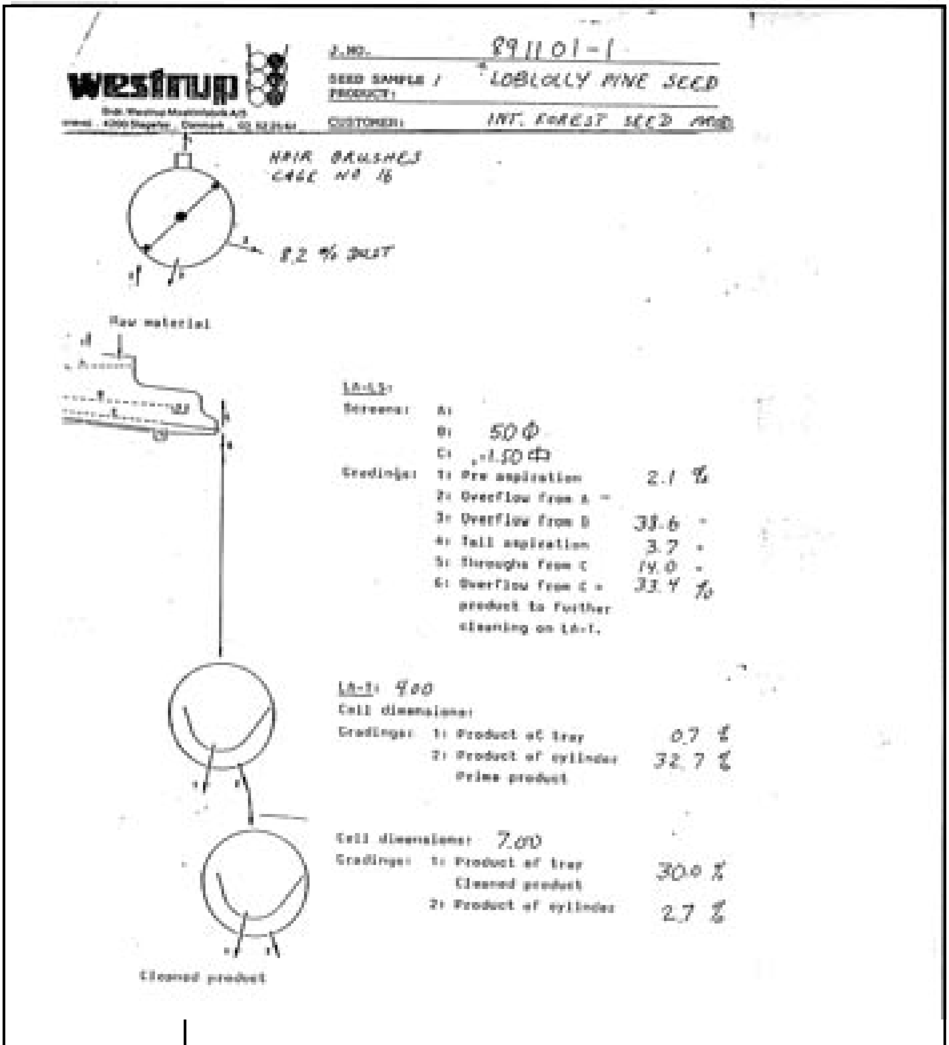


Figure A6.7. Dybvig fruit macerator for depulping fleshy fruits. Fruits to be depulped are filled into the hopper. During operation the spinner plate with two cross-bars rotate causing abrasion and tearing of the fruit flesh. The clearance between the spinner plate and bottom is adjusted so that cleared seeds or stones are retained; the fleshy material is carried between the spinner plate and bottom and removed through the outlet. A constant flow of water from the water tap helps washing away the fleshy material. After depulping the cleaned seeds or stones are removed by opening the shutter at the side of the hopper. Lining the inside of the hopper with hardware cloth increases the abrasion effect. Another refinement is to bolt a can, also lined with hardware cloth, on top of the spinner plate (Amata-archachai and Wasuwanich 1986, Karrfalt 1998).

Appendix A6.2. Two examples of a seed processing journal

A. This journal was developed during processing of *Pinus taeda*. Processing consists of de-winging in a brush dewinger, then cleaning on a mechanical sifting machine followed by two times cleaning in an indented cylinder with different cylinders. Technical specifications as these serve as guidelines for future processing of the same species.


westrup

J.NO. 891101-1

SEED SAMPLE / PRODUCT: LOBLOLLY PINE SEED

CUSTOMER: INT. FOREST SEED AND

HAIR BRUSHES
CAGE NO 16

8,2 % DUST

Raw material

LA-LS:
Screens: A:
B: 50 Φ
C: 1.50

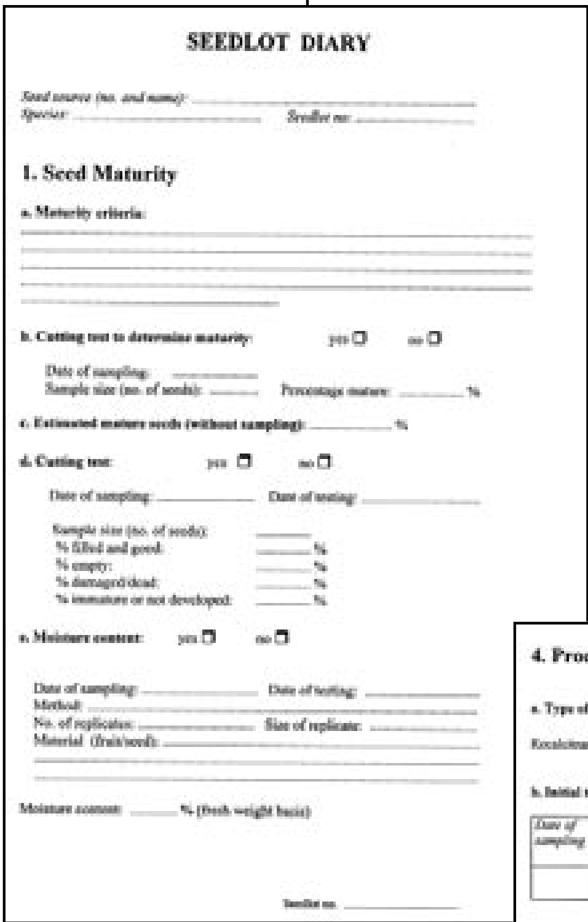
Gradings:
1: Pre aspiration 2.1 %
2: Overflow from A –
3: Overflow from B 38.6 "
4: Tail aspiration 3.7 "
5: Throughs from C 14.0 "
6: Overflow from C = product to further cleaning on LA-T. 33.4 %

LA-T: 900
Cell dimensions:
Gradings:
1: Product of tray 0.7 %
2: Product of cylinder Prime product 32.7 %

Cell dimensions: 7.00
Gradings:
1: Product of tray Cleaned product 30.0 %
2: Product of cylinder 2.7 %

Cleaned product

B. This journal for seed processing is a more general one that can be used for different tree species. It is part of Technical Note no.54 from Danida Forest Seed Centre (Poulsen and Thomsen, 1999). It is called a seed lot diary; two pages are shown here for illustration.



SEEDLOT DIARY

Seed source (no. and name): ....

Species: .... Seedlot no: ....

1. Seed Maturity

a. Maturity criteria:

b. Cutting test to determine maturity: yes ☐ no ☐

Date of sampling: ....

Sample size (no. of seeds): .... Percentage mature: .... %

c. Estimated mature seeds (without sampling): .... %

d. Cutting test: yes ☐ no ☐

Date of sampling: .... Date of testing: ....

Sample size (no. of seeds): ....

% filled and good: .... %

% empty: .... %

% damaged/dead: .... %

% immature or not developed: .... %

e. Moisture content: yes ☐ no ☐

Date of sampling: .... Date of testing: ....

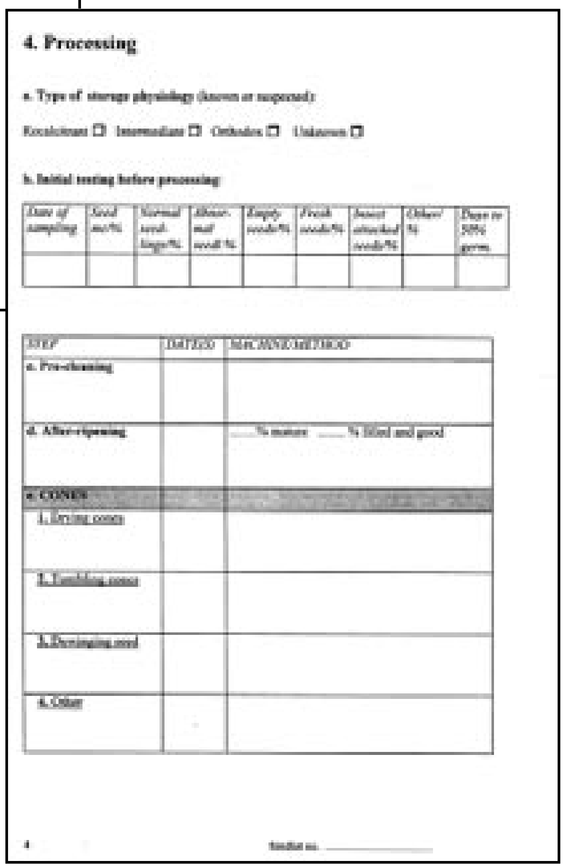
Method: ....

No. of replicates: .... Size of replicate: ....

Material (fruit/seed): ....

Moisture content: .... % (fresh weight basis)

Seedlot no. ....



4. Processing

a. Type of storage physiology (known or suspected):

Recalcitrant ☐ Intermediate ☐ Orthodox ☐ Unknown ☐

b. Initial testing before processing

Date of sampling	Seed mc%	Normal seedlings%	Abnormal seed %	Empty seeds%	Fresh seeds%	Insect attacked seeds%	Other %	Days to 50% germ.

STEP	DATE(S)	MACHINE/METHOD
c. Pre-cleaning		
d. After-ripening		..... % mature ..... % filled and good
e. CONES		
1. Drying cones		
2. Tumbling cones		
3. Dewinging seed		
4. Other		

4 Seedlot no. ....