Guide to handling of tropical and subtropical forest seed

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HANDLING OF FRUIT AND SEED BETWEEN COLLECTION AND PROCESSING

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

HANDLING OF FRUIT AND SEED BETWEEN COLLECTION AND PROCESSING

5.1 Introduction

Newly collected fruits and seeds are particularly susceptible to damage, primarily because they often have relatively high moisture content. Since loss and deterioration of seeds are irreversible, appropriate handling immediately after collection is crucial for the ultimate seed quality.

Susceptibility to and speed of deterioration depends on

- species
- condition of the seed at collection and
- the external environment.

Generally, the sooner seed can be processed the better. Therefore the seed should be delivered as quickly as possible to the seed-processing depot, where further handling takes place. During short seed collection expeditions close to the processing depot, where seed can be delivered every day, special field handling procedures can normally be omitted.

Hence, this chapter mainly applies to collection expeditions of longer duration, where seed is prone to deterioration before it can be delivered to the seed processing depot, and/or where quantity of fruits combined with limited transport capacity makes bulk reduction an economic imperative. The degree of field processing is determined by the necessity for bulk reduction and maintenance of viability. Field handling procedures are in principle similar to those undertaken at the seed processing depot, which will be described in detailed in chapter 6. However, since technical facilities are generally limited and the environment difficult to control in the field, processing in the field often has a quite different character than that conducted at the central depot. The purpose of field processing is not to obtain clean, storable seed but to ensure that the seed and fruit can be reduced in bulk for efficient and economic transportation to the central seed-processing depot.

5.2 Reduction of Bulk

Apart from very large seeds of dehiscent fruits it is almost invariably the fruits that are collected. Fruits are normally bulky compared to seeds. For example, a fruit of *Casuarina equisetifolia* weighs about 3 grams, its contained seeds around 0.08 g or about 2.5% of the fruit weight. In most eucalypts, seeds make up 2-4% of the fruit weight (Boland *et al.* 1980). Even larger differences are encountered when calculated on a volume basis, which is relevant in connection with transportation. For example, 10 litres of capsules, together with leaves and twig fragments of *Eucalyptus camaldulensis* may yield some 40-60 ml of pure seeds or only 0.50% by volume. Bulk reduction by depulping of drupes is significantly less, often around 40-60% - both when calculated on weight and volume basis.

Generally, twigs, leaves and other debris are, at the best, redundant material to transport and store, at the worst they are potentially detrimental to seed viability as they contain moisture and possibly seed pathogens. Whatever non-seed material can be easily removed should be removed, both to reduce bulk and the potential risk of seed damage. However, in small-fruited species like eucalypts a moderate amount of twig material is usually kept with the fruit at this stage as it increases the air space between the fruits and hence improves aeration (For. Com. 1994, ATSC 1995).

Extraction of seeds from dry dehiscent fruits like those of many Leguminosae, Myrtaceae and conifers is often easily and quickly done in the field provided weather conditions are dry. Mature fruits of these species will normally split open and release their seeds upon drying, sometimes with little additional mechanical impact like raking or shaking. Once the seeds have been released, empty fruits and debris can be removed and discharged manually or by raking.

It depends on the ease of extraction whether seeds of dry indehiscent fruits are extracted or not. Indehiscent fruits that require special extraction procedures, such as high temperature or threshing, are normally left intact after drying, and extraction is then conducted at the central depot.

Bulk reduction of fleshy fruits may be achieved by removing the fruit pulp, a procedure that also serves to avoid fermentation of the pulp with consequent reduction of viability (see below).

Many types of seed are more vulnerable to damage when extracted, e.g. recalcitrant seeds and seed with a thin fragile seed-coat. Possible bulk reduction by extraction should be undertaken with care to avoid hampering viability. Fruits, which must be after-ripened, should obviously not be extracted but maintained moist throughout field handling.

Some equipment for field handling is listed in appendix A5.1. In relation to bulk reduction, the equipment itself should be considered and balanced against the potential bulk reduction of the fruit. Semi-portable threshers may only be justified for relatively large quantities of fruits.

5.3 Maintaining Viability

Most pre-processing damage to seeds in the field is closely related to their moisture content. Accordingly, suitable management of seed moisture can limit some deterioration. The theory of seed moisture and drying principles, and measurement of seed moisture in the field are described in appendix A5.2 and A5.3 respectively.

A moisture content of 10-20% at the time of collection is normal for most orthodox seeds. Immature orthodox seeds and mature recalcitrant seeds have considerably higher moisture content, often 30-45%. Any moisture, whether in fruit pulp, in non-desiccated (immature) dry fruits, fruits collected in moist weather, or seeds with a natural high moisture content at maturity (recalcitrant seeds) implies a risk of deterioration. High moisture content creates an ideal environment for fungi and bacteria. Moist fruits and seeds respire, which creates heat and consumes oxygen. If the oxygen is depleted because of inadequate aeration, fermentation replaces respiration. The simplified biochemical equations of the two processes are as follows:

Respiration: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}$
Fermentation: $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 + \text{energy}$

The biochemical processes of both respiration and fermentation create heat. Since high temperature in connection with high moisture content tends to accentuate respiration or fermentation, the process can be self-accelerating, resulting in a combustion of the whole fruit or seed lot. Leaves, soil or any other debris with a high moisture content may add to the process. Fermentation of fleshy pulp may not in itself affect the seeds, but heat generated from the process may. Further, mould and other fungi starting to grow on dry fruits may hamper the subsequent extraction (Seeber and Agpaoa 1976). Therefore, during any prolonged storage in the field proper ventilation should be assured and the moisture content reduced as much as possible. Recalcitrant seeds impose a problem in this context since they are intolerant of desiccation. They must be dried down to the lowest possible levels for safe storage and maintained moist throughout storage (Tompsett 1987).

Temperature tolerance is closely connected to moisture content. Seeds with a high moisture content are much more sensitive to high or low temperature than dry seeds. Hodgson (1956, in Boland *et al.* 1980) found that moist seed of *Eucalyptus obliqua* lost viability within a few minutes when exposed to a temperature of 55°C while that temperature had little effect once the seed was dry. A temperature of 55°C is easily encountered under tropical sun. Recalcitrant seeds, which do not tolerate desiccation, are always sensitive to temperature extremes. Some tropical rain forest seeds do not tolerate temperatures above 35°C or below 20°C. The potential for temperature damage immediately after harvest depends on species and condition of the seeds. Highly recalcitrant seed and seed with high moisture content are most sensitive (see chapter 8 for details on viability).

Most dry orthodox seeds tolerate the temperature ranges normally encountered in the field. But for sensitive species fatal low temperatures may be encountered during passing or overnight stay at high altitude. Fatal high temperatures may be encountered if the seeds are exposed to direct sun, or if stored in e.g. vans, car boots or polythene sheeting or bags under direct sun. Overheating may also kill microorganisms like mychorrhiza and rhizobia, which are often collected together with seed (see chapter 13).

Most fleshy fruits need to have their fruit pulp removed in order to avoid fermentation. However, short storage of pre-mature fleshy fruits or fruits with a relatively dry fruit pulp, e.g. *Ziziphus mucronata* and *Grewia* spp. may not require depulping.

Recalcitrant seeds have a low tolerance to temperature extremes and desiccation. The degree of recalcitrance (i.e. tolerance level, see chapter 8) varies with species. Recalcitrant seeds may be contained in both dry and fleshy fruits. Excessive drying should be avoided and the seeds never exposed to direct sun. On the other hand, as the seeds normally have no dormancy, too high a moisture content may make the seeds germinate. The balance is very difficult to achieve, especially under field conditions. The best solution is to reduce the transit period as much as possible or, if germination cannot be avoided, to keep the germinated seeds in a stage where they can be delivered directly to the nursery.

It is essential that the seed collector knows the basic physiology of the species he/she collects, and takes the appropriate actions to maintain viability from collection until the seeds are delivered to the processing depot.

5.4 Maintaining Identity

Fruits and seeds unloaded and loaded several times during seed handling are prone to be mixed up and lose their labels and identity unless caution is observed. Strict practical routines help minimise the risk of losing the identity during field handling (reference is made to chapter 14 on documentation):

1. Always use two labels, one fixed to the outside of the container or bag, and one inside together with the seed. The labels and ink should be waterproof. For identical seedlots, write total number of containers together with container number, e.g. 1 of 3.

2. If bags or containers are emptied e.g. for drying the seeds, keep the container together with the seeds and put them back into the same container after each event of handling. This also prevents possible contamination with left over seeds in the container and spreading of pathogens.

3. As bulk is reduced, some containers may become redundant. Surplus labels should be removed and the figure indicating total number of containers corrected on the remaining labels (e.g. 1 of ~~3~~ 2).

4. When fruits or seeds are dried in the open, labels must be secured from blowing away.

5.5 Hygiene and Contamination

Foreign seeds or micro-organisms can contaminate a seed lot. The former is especially risky if the seeds cannot be separated later because the seeds are very similar, e.g. two provenances of the same species. Contamination may occur if seeds are stored in the same container which has not been appropriately cleaned, processed with the same equipment, or if seeds from one seed lot accidentally blow, slip or in other ways make their way from one container, bag or tray to another. Small seeds like eucalypts and casuarinas are especially risky since they tend to stick into folds, sewing and corners of bags, containers, trays or other equipment. Small seeds can be removed by thorough cleaning, e.g. dry or wet brushing. Bags should be turned inside out when cleaned. Containers and trays should be free from holes or damages, both to avoid seeds being lost through perforations and to reduce risk of contamination from one seed lot to another (ATSC 1995).

Fungi cannot be completely excluded, but by keeping equipment and containers clean and dry, their multiplication can be controlled.

5.6 Practical Field Processing and Storage

During collection expeditions of several days' duration in one area it is advisable to affiliate with a local forest department, agricultural unit or other permanent base, where the fruits can be stored and pre-processed every day rather than keeping them in a truck exposed to adverse weather conditions and with danger of overheating. If alternatives exist, the base should be chosen where climate and other conditions are optimal for temporary storage and processing, i.e. cool, dry and windy for orthodox seeds (Stubsgaard and Moestrup 1991). Availability of electricity and running water are facilities that can greatly facilitate processing and make it more efficient.

5.6.1 Drying of fruits and seeds

If fruits are kept separate according to individual trees, it is important that the fruits are not mixed during pre-drying and that identity labels are kept with the fruits at all times. Fruits or cones stored in loosely woven hessian sacks or similar material may dry by natural air circulation through the fabric.

Quicker and more uniform drying is achieved by spreading out fruits or cones on concrete floors or sheets, or, in order to improve air circulation, by drying them on elevated sheets or trays (see appendix A5.1 for field equipment). The latter also prevents moisture from the ground from ascending and delaying the drying process (Aldhous 1972, Stein *et al.* 1974). To assure fast and uniform drying, the layer of fruits should be thin and the fruits turned regularly. Increased air temperature with concurrent decrease in relative humidity can be achieved by covering desiccation trays with a layer of thin transparent polythene sheet (Bolan *et al.* 1980), (see fig. 6.3). This will create a greenhouse effect but it is important that the sheet is not put directly on top of the seeds as it may impede air circulation (Stubsgaard and Poulsen 1995). The relation between temperature, relative air humidity and seed moisture is described in Appendix A5.2.

Because seeds with high moisture content are more prone to heat damage, direct sun-drying should be avoided until the moisture content has gone down. Initial drying under shade is recommended; once the moisture content has lowered, the seeds may be exposed to full sun-drying. Fruits of species with recalcitrant seeds should never be sun-dried. Under high humidity condition, shade drying may be quite difficult and depending on appropriate air circulation. If natural wind is insufficient, fans may improve circulation.

Outdoor drying implies a risk that the seeds are wetted during occasional showers, blown away by wind (beware of the label), or are eaten by birds or other animals. As temperature falls at night with concurrent increase in relative air humidity, seeds should be covered to prevent them from regaining moisture.

Fruits and seeds should not be left outdoors unattended for a long time if there is a risk of adverse weather conditions or foraging animals. Domestic goats are especially fond of acacia pods, and rodents like rats and mice readily attack exposed fruits and seeds as well as those stored in sacks or bags. Camping areas in wildlife sanctuaries or parks often house animals that are accustomed to human presence and that may aggressively attack any potential food source. Baboons, monkeys, bears and even elephants can in some areas be a nuisance and make any on-site seed handling impossible.

Dehiscent fruits should be inspected and disposed of once they are empty. Large fruit debris can be removed manually or by rakes. Wire mesh sieves are appropriate for most small seeded species.

5.6.2 Seed extraction from dry indehiscent fruits

Seeds from most indehiscent dry fruits are normally not extracted in the field but are dried down to safe moisture content and then stored in sacks or bags with appropriate ventilation.

Extraction may be considered for the few species with relatively fragile or bulky pods like *Acacia tortilis*. Seed may here be extracted by beating sacks containing pods with sticks until the fruits open or disintegrate (Doran *et al.* 1983) (fig. 5.1). Large quantities can be processed by beating with sticks or flails on a threshing floor. Very large pods may be split open by hand. Where portable threshers are brought along (appendix A5.1), a wide range of species may be partly or fully extracted in the field. It should be noticed that some seeds are sensitive to mechanical treatment, and the impact of e.g. beating or threshing on viability should be considered before the seeds are exposed to a mechanical extraction (see further discussion chapter 6).

Species with serotinous fruits will dehisce only upon extreme heat, e.g. fire. In Australia seeds of *Banksia* are extracted by barbecuing the fruits over a wire mesh, then submerging them in water (Kabay and Lewis 1987).

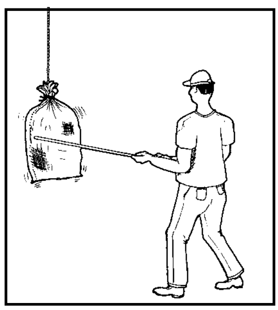


Figure 5.1.
Seeds extraction from fragile or bulky indehiscent pods by beating fruit sacks with sticks.

5.6.3 Depulping of fleshy fruits

Fleshy mature fruits like berries and drupes should have their fruit pulp fully or partly removed before drying. For most fleshy fruits the easiest way of extraction is to soak the fruits in water overnight, macerate them e.g. on a wire mesh and rinse them with water to remove as much pulp as possible (see section 6.4.2). Alternatively, the soaked fruits are macerated while submerged, e.g. by gently pounding them in a mortar with a pestle (without cracking the seeds) (Albrecht 1993, Kioko *et al.* 1993). When macerated fruits are left in the excess water, the seeds tend to stay at the bottom while the soft fruit material tends to float and can be skimmed off (Seeber and Agpaoa 1976). If large quantities of fleshy fruits need to be processed, small manual or powered depulpers may be feasible during field operations (see chapter 6).

Stones of drupes are normally not prone to mechanical damage during depulping, but some berries and other soft fruits may be more sensitive. Any fruit pulp adhering to the seeds or the pyrene after maceration is usually of minor importance since it will dry out once the skin (exocarp) and most of the pulp have been removed. Complete cleaning may be necessary during subsequent processing.

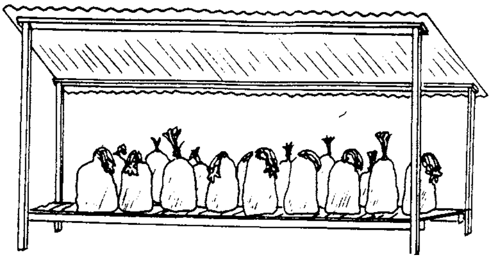
Seed storage type	Fruit type	Viability maintenance	Bulk reduction (extraction)
Orthodox	Dry dehiscent	(sun) drying	Drying - shaking - sifting or manual removal of fruit parts
	Dry indehiscent	(sun) drying	Flailing, pounding or threshing - sifting or manual removal of fruit parts
	Serotinous	(sun) drying	Barbecuing - shaking -sifting
	Fleshy	Thin pulped: (sun) drying Others: depulping by pounding or washing	Depulping
	Immature (any type)	Moist storage	Not applicable
Recalcitrant	Dry fruits	Moist storage	Drying until dehiscence, sifting or manual removal of fruit parts
	Fleshy fruits	Depulping, moist storage	Depulping

Table 5.1. Summary of seed handling in the field.

5.6.4 Temporary field storage

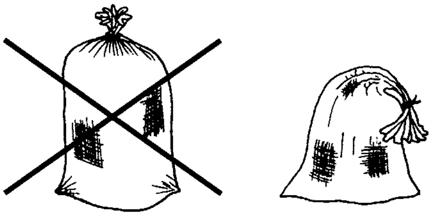
Storing at a field station is normally restricted to the short period during seed collection and pre-processing. Under humid conditions it may not be possible to reduce moisture content to less than 10-15% for orthodox seed. Such seed is still susceptible to heat damage. Some practical guidelines for temporary storage are listed in fig. 5.2.

Temperature within large containers may be measured by a thermometer inserted in a pipe which can reach into the centre of the container (Fig. A5.8). If a temperature increase of more than say 5-8°C above the outside temperature is measured, unloading or mixing may be advisable.

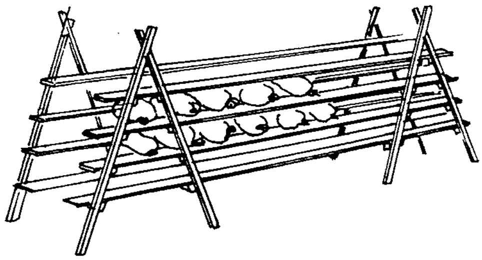


1. Fruits and seeds should be stored under shade and shelter to protect from direct sunlight, heating and rain. If containers are not waterproof, they should be raised slightly to avoid moisture from the ground.

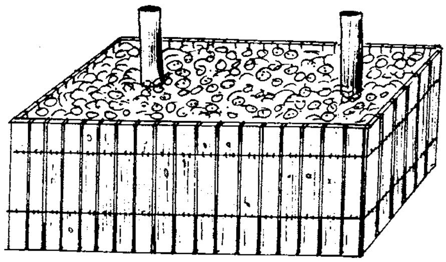
2. Bags and containers should consist of material that allows maximum air circulation without spilling seed, e.g. baskets or hessian bags.



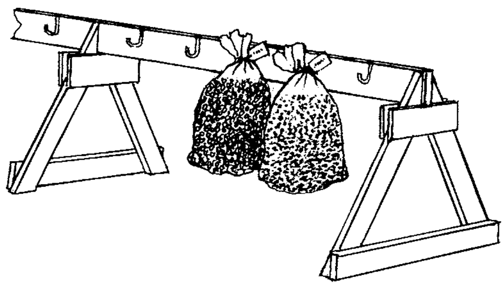
3. Bags and containers are filled to max half-capacity; bags and sacks are tied loosely. This facilitates regular mixing of the fruits and allows expansion of entire fruits such as cones.



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



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



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

Figure 5.2. Six methods for temporary storage under field conditions.

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

5.7 Conditions During Transport

Most fruits and seeds are transported by road from the collection site to the processing depot and often go together with the collection team. Unaccompanied rail, truck or bus transport may occasionally be feasible, e.g. midway during a long collection expedition. In these cases, where sensitive material are left in the hands of non-professionals with little knowledge and sometimes little interest in how to handle seeds, special precautions must be taken to avoid damage, i.e. appropriate instruction to the transport company.

Transport time from collection site to processing depot should be as short as possible, since it is difficult to maintain a proper environment during transportation. For example, bags and containers must inevitably be piled at this stage, and several factors are difficult to control during transport. Safety measures depend on the transport time, and the type and condition of the fruits or seeds. Some general guidelines are listed here:

1. Assure optimal ventilation for orthodox seeds, e.g. by transport on open loads rather than in closed vans.

2. Protect seeds from moisture by covering with a tarpaulin or other waterproof material.

3. Avoid parking transport vehicle directly in the sun. This is especially dangerous for recalcitrant seed, moist seed and possible microsymbionts.

4. Avoid desiccation of recalcitrant seeds. The air circulation created by driving pick-ups and trucks can be very desiccating on open loads. Protect the seed against desiccation by storing them in moist material like sawdust, or placing moist material on top of the containers.

5. Protect cold-sensitive seeds like recalcitrant lowland rainforest seed if the route has to pass high altitude areas.

6. Transport of sacks placed in cardboard boxes helps to insulate and protect the sacks and contents.

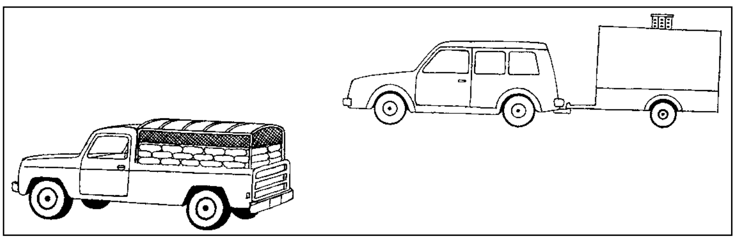


Figure 5.3. Seeds should be protected from adverse environments during transport. See the general guidelines in this section.

5.8 Temporary Storage at Seed Processing Depot

Fruits arriving at the processing depot may typically be stored for some length of time until they can be processed. Limited space, manpower, processing equipment or capacity are typical bottlenecks. Where e.g. drying and pre-processing have been undertaken in the field, storage at the processing depot may just be a continuation of the field storage. However, any fruit or seed lot should be inspected upon arrival at the processing unit in order to judge further appropriate handling. The potential dangers of deterioration are typically the same as during field handling, viz. fungi, fermentation, germination etc.

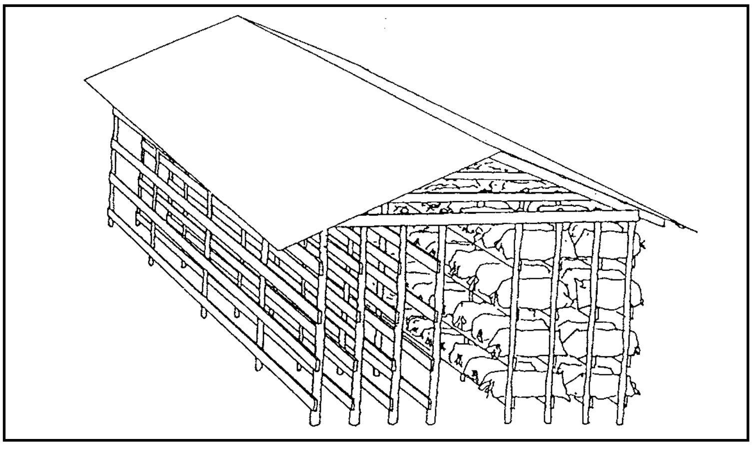
Temporary storage at the processing depot is often of longer duration than field storage. However, the storage environment is normally easier to adjust, e.g. using shelters, cold storage or protection against predators. Although temporary storage is intended to maintain the fruits and seeds at the stage of their arrival, biological processes will continue. Dry dehiscent fruits will typically open and release part of the seeds. That will necessitate storage that protects identity and prevents loss e.g. seeds blowing away or falling out of containers.

If the whole seed lot is immature when collected (chapter 4), it should be after-ripened. Often a fraction of the fruits will be immature even if it was not intended. Since immature fruits of dry-fruited species have a high water content, which may affect the viability of the whole seed lot negatively, their removal is often desirable. If these fruits are biologically capable of after-ripening and facilities are available, they may be exposed to after-ripening (section 6.3). If not, or if sufficient mature fruits are available, they may be disposed of.

Branchlets, twigs and leaves should preferably be removed before temporary storage. For example, cladodes of casuarinas disintegrate when dry and are difficult to separate from the seeds during later processing (Turnbull and Martensz 1983).

Fleshy fruits with relatively dry pulp may be temporary storable when dry. Others must be depulped immediately and further processing may be postponed. As during field storage and transport the main point is to avoid decomposition of the pulp during temporary storage. Chemical inhibitors in the fruit pulp may prevent germination, and in species with recalcitrant seeds where temperature and moisture cannot be brought sufficiently down to prevent germination without hampering viability, maintenance of the inhibitory substances in the fruit may be a way of avoiding pre-processing germination. However, in some species such as *Prunus africana* immediate depulping is mandatory to maintain viability (Schaefer 1990).

Figure 5.4.
Sheltered storage shed
for temporary storage
of cones prior to processing.



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Appendix A5.1. Field processing equipment

As with any other gear to be used in the field, processing equipment should be kept to a minimum. Necessary equipment should be light, small and possibly easily dismantled to reduce its size. The type of equipment needed depends on the type of fruits collected, the type of processing and the quantity to be processed. Some commonly used items of processing equipment are listed below. Most of them can be made locally, and modified to the conditions needed. More processing equipment is presented in chapter 6 and appendix A6.1.

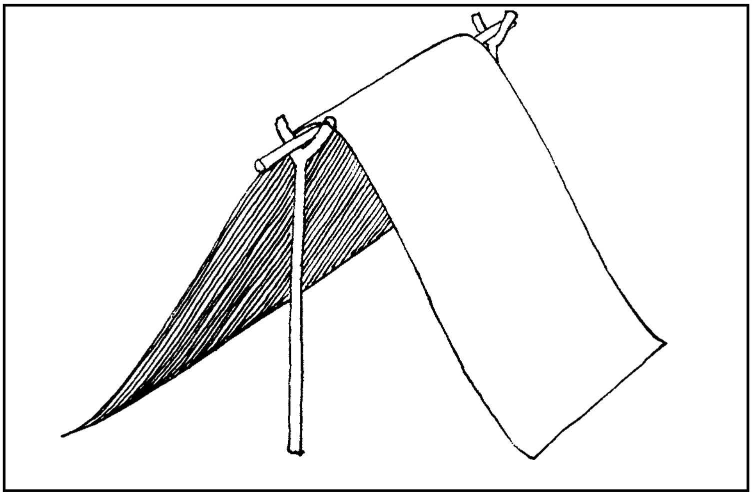


Figure A5.1. Waterproof tarpaulins. Many types and sizes are available, and have multiple uses in the field. They may be used during collection (chapter 4), for drying on the ground or for shelters. A max width of 5m for the narrowest width is recommended so that fruits can be reached with rakes without stepping on the tarpaulin.

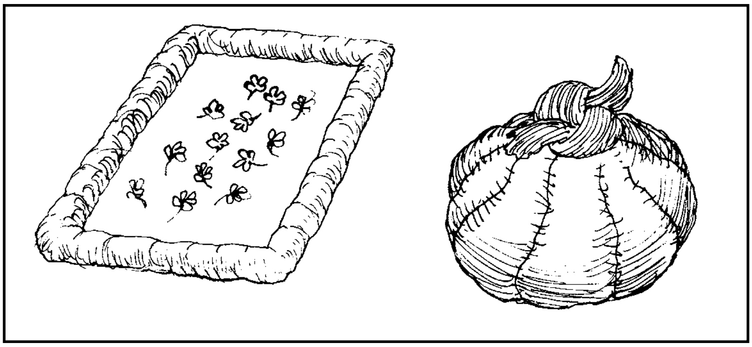


Figure A5.2. Canvas sheets. Most common dimension is 2x2 to 3x4 m. They are used in the same way as tarpaulins for collection and drying. Because of their thin fabric they are easy to fold and tie, unfold and untie during work.

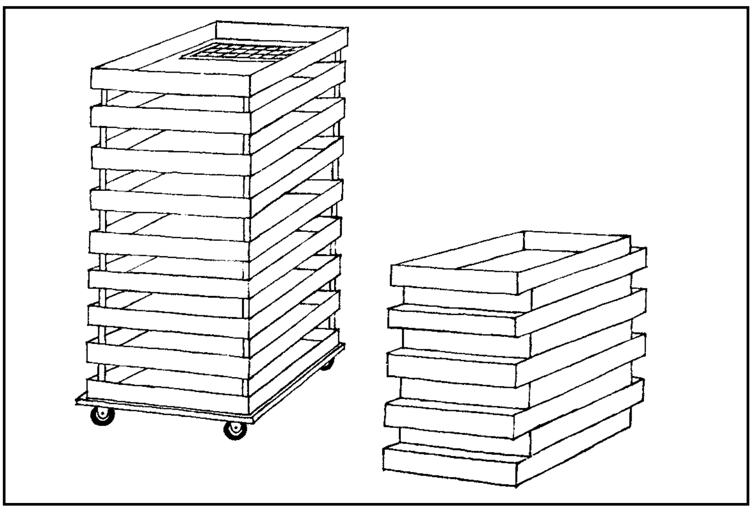


Figure A5.3. Wood framed trays. Type and size depend on fruit and seed size. A type for multiple use consists of a wooden frame with bottom made of wire mesh. The size of the mesh depends on seed size. They should be fine-masked enough to retain the seed to avoid them falling from one tray to the next. Rectangular wooden trays are constructed so that they can be stacked with minimum space during transport, yet stackable with space for air circulation when used during drying.

Figure A5.4.
'Hammocks'. Hammocks are made of wire mesh, e.g. large meshed chicken nets. Size e.g. 1½ - 2½ x 2½-4m. Each end of the 'hammock' is fastened to a pole, and the hammock is rolled up during transport. The 'hammock' is covered with a canvas sheet containing the fruits / seeds when used for drying. The sheet must be clipped to the hammock with cloth-pegs to prevent it from blowing away.

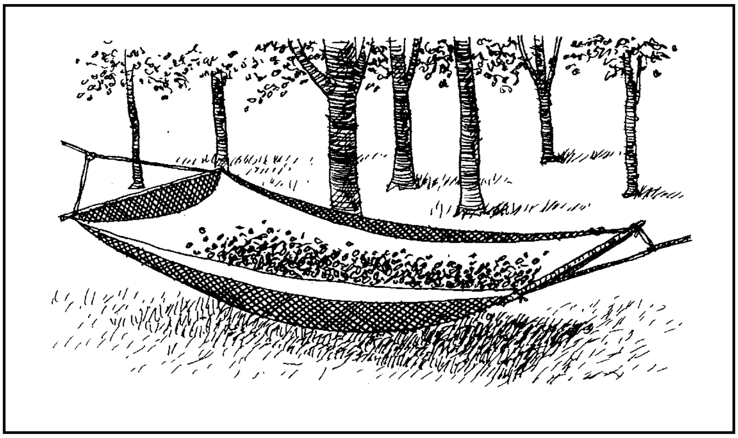


Figure A5.5.
Mortar and pestle. Standard maize mortars are widely used in large parts of Africa south of the Sahara. Most mortars have a volume of 6-10 litres. The pestle is a 1.75-2 m long, 6-6 cm diam. hardwood pole. The mortar and pestle are used for pounding fleshy fruits and for cracking indehiscent dry fruits of e.g. *Acacia* and *Prosopis* spp.

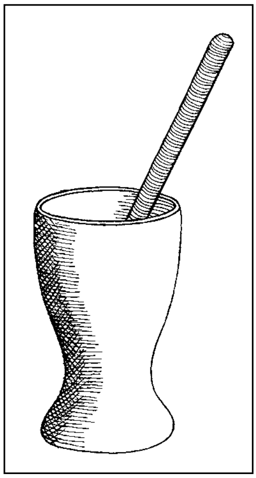


Figure A5.6.
Wire net screens. Wire net trays may be used as screens if the mesh width is appropriate. Screens may be used for pre-cleaning and depulping. For pre-cleaning, the mesh width should be just over seed size, so that the seed pass through and fruits and larger matter are retained. For depulping, the mesh width should be just under seed size so that seeds are retained but fleshy material can be squeezed or washed through.

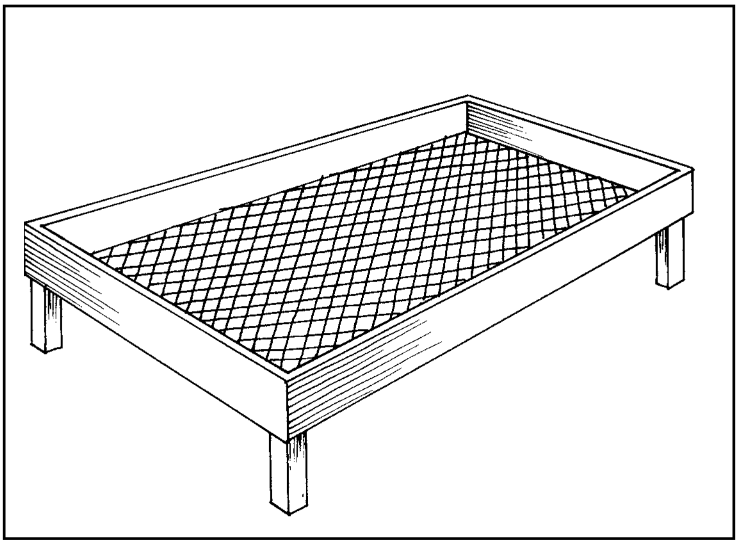


Figure A5.7.
Water buckets or drums. Apart from use for transport and storage of water, water containers are used for de-pulping and separation of fruit skin (which floats) and seeds (which sink).

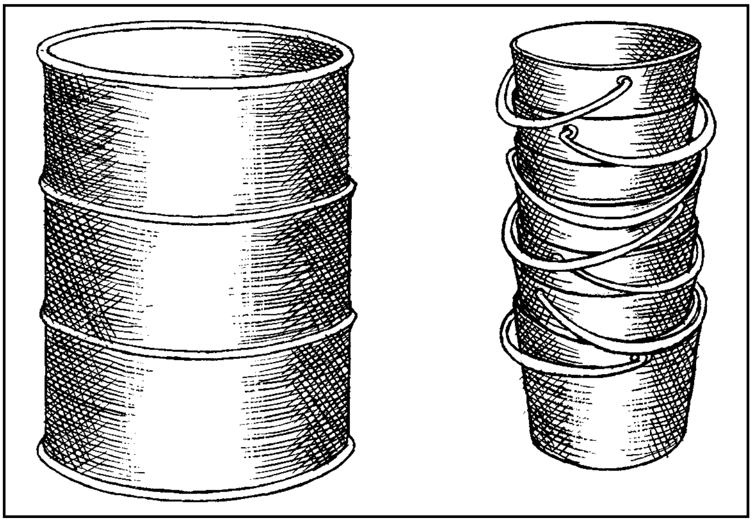


Figure A5.8.
Thermometer to be used for monitoring temperature inside piled fruit or seed lots.

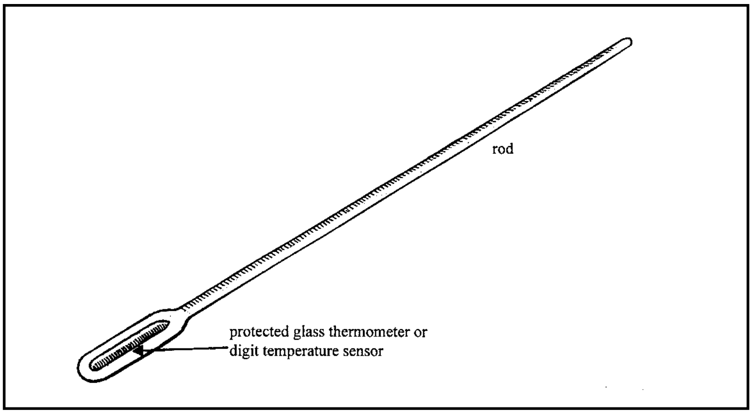
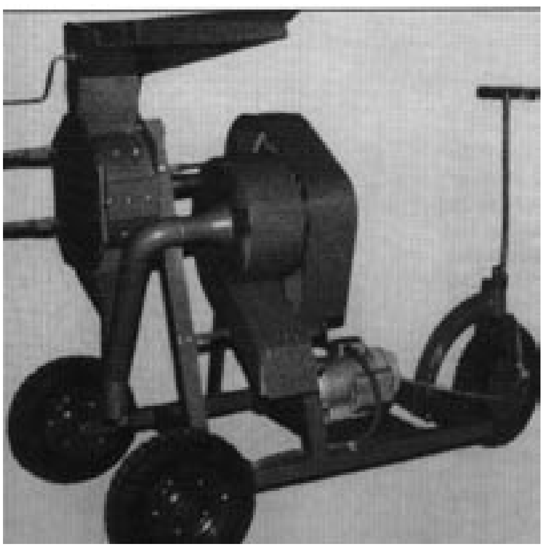


Figure A5.9.
Portable fruit thresher powered with electric or fuel engine. Kimseed©, Australia



Appendix A5.2. Seed moisture and principles of seed drying

The physical relationship between seed moisture, temperature and relative humidity forms the basics of seed drying.

1. Temperature and humidity. The maximum amount of water that can be contained in atmospheric air depends on temperature: the higher the temperature the more water it can contain. If the air contains the maximum amount of water vapour at a given temperature, it is said to be saturated. The relation of temperature and saturation is not linear but follows a curve as shown in figure A5.10. Usually the air is not saturated but contains less water than possible. The actual amount of water is expressed as the relative humidity (RH). RH indicates the actual water content as a percentage of that of saturated air at the same temperature. For example, if air at 20°C contains 10g water/kg dry air where its capacity (saturated air) is 15g/kg dry air, its RH is 10/15X100%=67%. Fig. A5.10 shows the relationship between saturated air (RH=100%), temperature and RH.

   If the temperature of air goes up or down and it contains the same amount of water vapour, its RH changes accordingly. For example, if air at a given humidity (e.g. 70%) is warmed up (e.g. from 20 → 35°C), RH drops (in the example to 30% RH). Opposite, if the temperature of the air drops (e.g. at night), RH increases. If the initial RH was high or the drop in temperature large, the air may reach the saturation point, where RH =100%. This is also called the dew point since further drop in temperature will cause condensation of the water vapour into dew droplets.

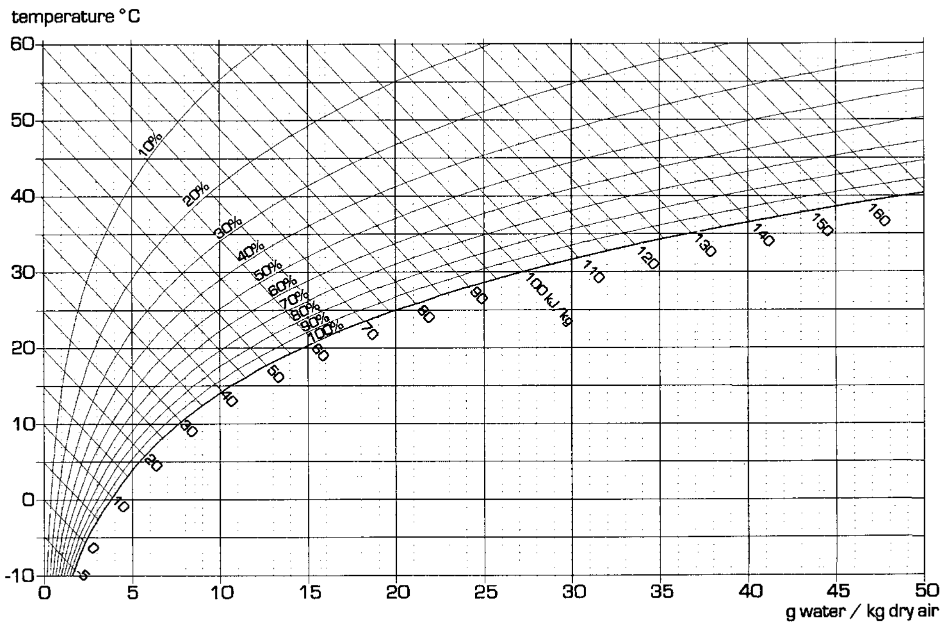


Figure A5.10. The relation between temperature and air humidity.

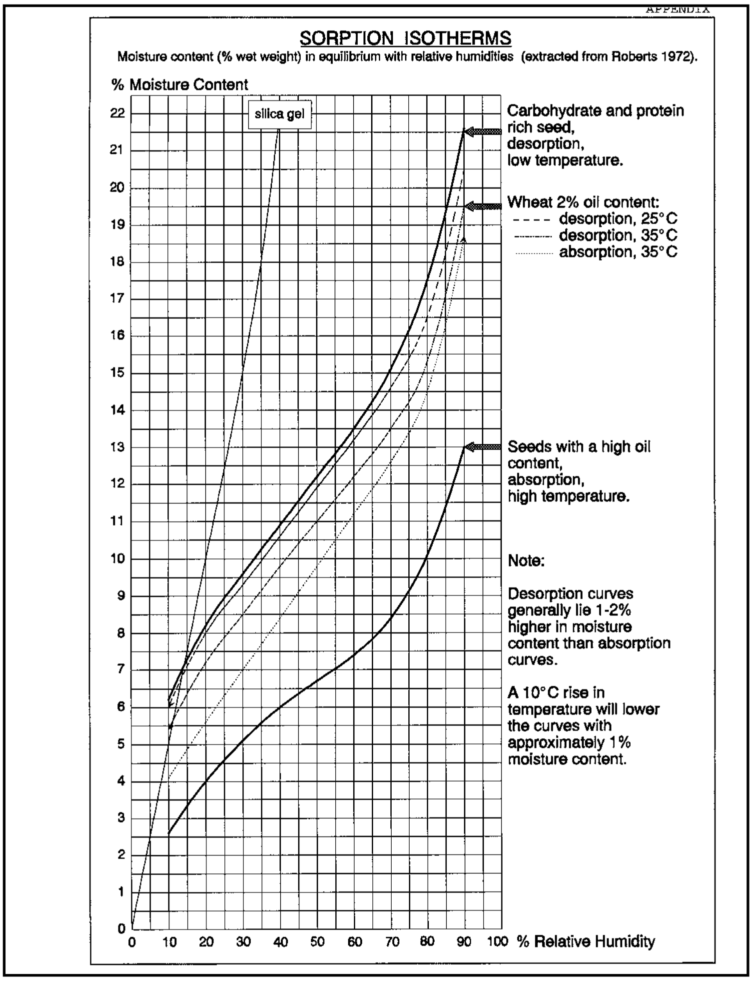
2. Seed moisture and relative humidity. Water in seeds (moisture content, m.c.) tends to be in equilibrium with atmospheric water (RH) around the seed. If the air is dry and the seed moist, water will tend to move from the seed to the air; the seed dries and the air around becomes more humid. If the air is humid and the seed dry, water will tend to move in opposite direction, hence the seed gains moisture.

   The larger the difference between RH and the equivalent seed moisture at the same temperature, the quicker the water movement will take place towards equilibrium. Therefore, the lower RH of drying air, the quicker the seed (or fruit) will dry. A warm air current with low RH is thus the most effective for drying.

   The equilibrium exists immediately around the seed. If the air around the seed is replaced by ventilation, a new equilibrium will establish with the new air now surrounding the seed. The faster the humid air is removed and replaced with dry air, the quicker the seed will dry. Therefore air circulation by natural wind or artificial ventilation promotes drying.

   Actual moisture content in equilibrium with air humidity at a

Figure A5.11. Equilibrium moisture content for different types of seed (Roberts 1972).



given temperature depends on species. Examples of equilibrium moisture content are shown in fig. A5.11.

3. Seed moisture and temperature. Temperature influences seed moisture in two ways. Partly via the above relation to RH. Partly directly by evaporation. As temperature increases, liquid water from the seed will evaporate.

Absorption and desorption of water are influenced by the seed or fruit size, and the structure of the fruit or seed-coat. Small seeds and fruits absorb or desorb faster than larger ones because the surface area is large relative to the volume, and the distance of migration of water is shorter. The anatomy of the seed (or fruit) determines how fast water can migrate from the interior to the outside during drying. A thick or dense structure is likely to restrict water movement. Tompsett (1987) found that seeds of *Dipterocarpus intricatus* dried to 7 % m.c. in a week, while seeds of *D. obtusifolius* retained 30 % m.c. after 5 weeks in the same drying room environment. The extreme case is in legumes where the seed-coat becomes impermeable to water. As the cells shrink during drying, water movement becomes constricted. That can cause the so-called ‘case hardening’ of cones where the inner part of the cones and the seeds remain moist because of too fast drying. The outer cone cells have collapsed and form a physical barrier to further desiccation.

With progressive drying the forces resisting desiccation of the cells increase. As the moisture content decreases, the remaining water is ‘bound’ to the cell constituents and macromolecules in the cells and becomes practically immobile (Bewley and Black 1994). Drying to low moisture content is consequently difficult and high temperature and dehumidified air may be necessary.

Absorption and desorption curves of fig. A5.11 differ. That means that while the seed relatively easily lose water at high temperature and low RH, absorption is much slower. In other words: seeds are often more likely to lose water during dry conditions than re-gain it under humid conditions. In legumes a special structure of the hilum, the hilar valve, has been described by Hyde (1954). The function of that structure is to allow water to leave the seed while water is unlikely to enter. Hence the seeds tend to establish equilibrium with the driest atmosphere they have been exposed to.

Type of storage tissue in the seed also influences moisture content. Nutrients are stored in seeds mainly as sugars, starch, protein and fat (oil). Simple sugars prevail in some extremely recalcitrant seeds but are rare in orthodox seeds. The four components differ in their water affinity, sugar being the most hygroscopic (binding most water), followed by protein, starch and oil in decreasing order. Hence, at the same RH seeds with a high oil content will contain less moisture than seeds with low oil (and high protein or starch) content.

Because of the differences in anatomical structure and storage tissue of seeds the equilibrium moisture content differs between species.

Certain chemicals have the ability to absorb moisture from the air at relatively low RH. One of the most common ones is silica gel, the equilibrium moisture content of which is shown in fig. A5.11. As silica gel absorbs moisture, RH of the surrounding air decreases. Seeds kept in a closed container together with silica gel will thus obtain moisture content in equilibrium with the air, dehumidified by the silica gel. Storing seeds with silica gel in order to keep them dry is practically applicable to small seed lots, e.g. stored in glass jars.

Appendix A5.3. Seed moisture meters

For exact measurement of seed moisture content, e.g. in connection with seed testing, the ISTA oven method (see section 10.3.4) must be applied. During field handling and processing where further operations depend on a quick result of the measurement, less accurate quick portable moisture meters are applicable. Several models are available. They are normally used for agricultural seed but may, with appropriate calibration, be used for forest seed. The principle in two types of moisture meters is described here. They measure the electric properties of seed moisture in one of two ways: (1) Conductivity, (2) Capacitance.

1. Conductivity measures the electrical resistance of seed material between two metal surfaces in a measuring chamber.
2. Capacitance measures the ability of seed material to act as a condensator, i.e. store electrical charge.

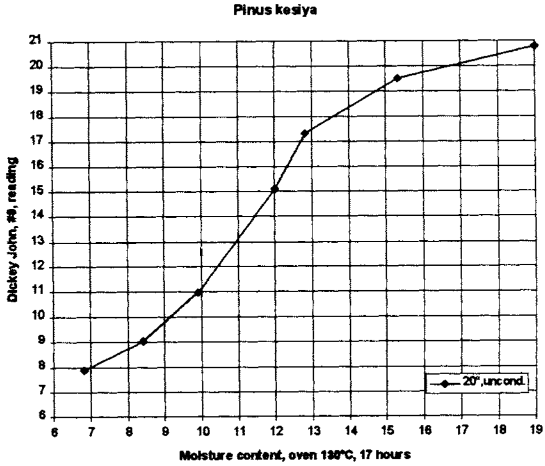
'Seed material' in either test may be either entire seed or homogeneous ground material. The latter gives the more precise result. Both conductivity and capacitance increase with increased moisture content. The exact relation of the reading of the instrument to actual seed moisture, as determined by the ISTA oven method, is called calibration. It differs from one species to another and must be established before the instrument can be used for a particular seed type. Calibration should encompass the range of moisture contents normally encountered for the species, i.e. typical 6-25% for orthodox seed and 20-50% for recalcitrant seed.

Once the calibration table or curve has been established, any reading of the instrument can be easily converted to actual moisture content.

Figure A5.12. Seed moisture meter.

Figure A5.13.
Example of calibration of seed moisture meter. A. Calibration curve. B. Calibration table.

A



B

Dickey John multigrain	
Species: *Pinus kesiya*	
20°C, unconditioned	
Setting: #9, Corn	
Reading	MC%
8.00	7.00
8.50	7.70
9.00	8.40
9.50	8.80
...	...
...	...
20.00	16.80
20.50	18.00