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EASY GUIDE TO CONTROLLING SEED MOISTURE DURING SEED PROCUREMENT

by

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1. INTRODUCTION

As soon as seeds mature on the mother plant, they begin to deteriorate. The rate of deterioration depends on the environmental conditions inside and around the seeds. This deterioration will eventually lead to loss of viability or seed death if the seed is not able to germinate.

Drying is part of the natural dispersal of many tree fruits. For instance, dehiscent pods and cones release their seeds only upon drying. The most important factor controlling how fast the seeds of these species deteriorate is their moisture content. Too much drying may on the other hand kill seeds of other species.

All seeds, whether they can be dried or not, should be collected when they are mature. Immature seeds do not have as high quality and do not tolerate drying as well as mature seeds. Fruit colour and seed moisture content are good indicators of maturity.

In order to obtain and maintain good seed quality it is therefore important to know the biology of the seed and to manage the moisture content of seed accurately during processing and storage.

This technical note covers the following subjects without going into the theoretical background: a short introduction to the physiological effects of moisture content on seed storability; how moisture content is measured; how the temperature and relative humidity affect the drying process; simple drying methods that do not involve control of the humidity of the drying air; and choice of containers to use during storage.

2. SEED MOISTURE CONTENT AND STORABILITY

It is crucial for the survival of animals and plants to keep a high, stable level of water in the organism. In humans and green parts of plants, the major part of the organism is water. Though some seeds seem very dry when they are collected, the water content, usually called moisture content, of seed is a very important factor to consider in relation to storability and survival of the seed.

Many seeds can be dried to very low moisture contents and may be stored that way for years, they are called **orthodox** seeds. Other seeds, often tree seeds from the humid tropics, cannot be dried, or only slightly dried. They are very difficult to handle and store and are therefore called **recalcitrant** seeds.

2.1 Orthodox Seeds

This group includes all seed which desiccates naturally on the mother plant; for instance most agricultural crop seed. If a seed can be dried without losing viability, it can be stored for years with a low moisture content because the life processes in the seed are slowed down. At moisture contents above 20 % seed respires actively and uses food reserves quickly, and at even higher moisture contents seed germinates given the right temperature.

The period of time orthodox seed can be stored before it loses capacity to germinate depends mainly on seed moisture content and temperature during storage. A rule of thumb is:

storage life of seed is doubled for each 1% decrease in moisture content, and doubled for each 5°C decrease in storage temperature.

For instance: drying orthodox seed from 9% moisture content to 8% may double the period you can keep it in store at a given temperature. Keeping orthodox seed at a low moisture content during storage is much cheaper, and has potentially much greater effect on prolonging possible storage period or keeping seed quality intact, than many other precautions.

Whereas agricultural crops are sown the next season and generally only stored for half a year, tree seed may be stored for longer periods.

2.1.1 Normal storage conditions

Long term storage
For long term storage, optimal storage conditions for orthodox species are used. This is, with very few exceptions, 4-6 % moisture content and the lowest economically possible temperature. As normal freezing equipment usually is easily accessible (either as domestic freezers or as a conventional freezing store), - 18°C will normally be used.

Because of the expenses involved, long term storage is only used for small seed lots as gene resource conservation, storage of reference material in breeding programmes, or for rarely fruiting species.

Medium term storage
Storage of tree seed for more than one year is usually done at a seed bank.
As seed lots of some species may amount to several tonnes, it is not possible to provide optimal storage conditions in all cases. Usually the compromise would be to store seed at 6-8 % moisture content in a cold store at 4°C. Hard-coated species with a naturally long life may be stored at 6-8 % moisture content in cool well-ventilated rooms for some years.

Less than one year
For storage until the first-coming planting season, orthodox seeds should be stored at below 8% moisture content and the lowest possible temperature. Under normal conditions this would be in containers impermeable to water vapour in the shade in a cool house or in a room with air conditioning if cold storage space is not available.

2.2 Recalcitrant Seed

Recalcitrant seeds generally store best at 15°C and with a moisture content few percent under the moisture content the seeds have when they are collected. Low moisture contents and (for tropical species) low temperatures damage the seeds.

For truly recalcitrant species minimum moisture contents will often be around 35-40%. There is also an 'intermediate' group (between orthodox and recalcitrant) that typically will accept drying down to 10-20% moisture content. Examples are given in Appendix 3.

Even at optimal conditions for seeds of tropical species in this group survival is typically limited to a few weeks or months.

Actual storage of recalcitrant seed is therefore usually not realistic if the seed is sensitive to low temperatures. Storage of these recalcitrant species amounts to keeping them alive during the short period until they are sown.

You may look upon recalcitrant seeds not as ordinary seeds but small germinating seedlings or sprouts; and they should be treated as such.

2.3 Storage Environment

Moisture content and temperature during storage also influence the potential survival of the seeds in store in other ways than setting the rate of respiration. Figure 1 (redrawn from Roberts, 1972) illustrates the combination of moisture content and storage temperature where storage environment allows other factors to threaten longevity of orthodox seeds.

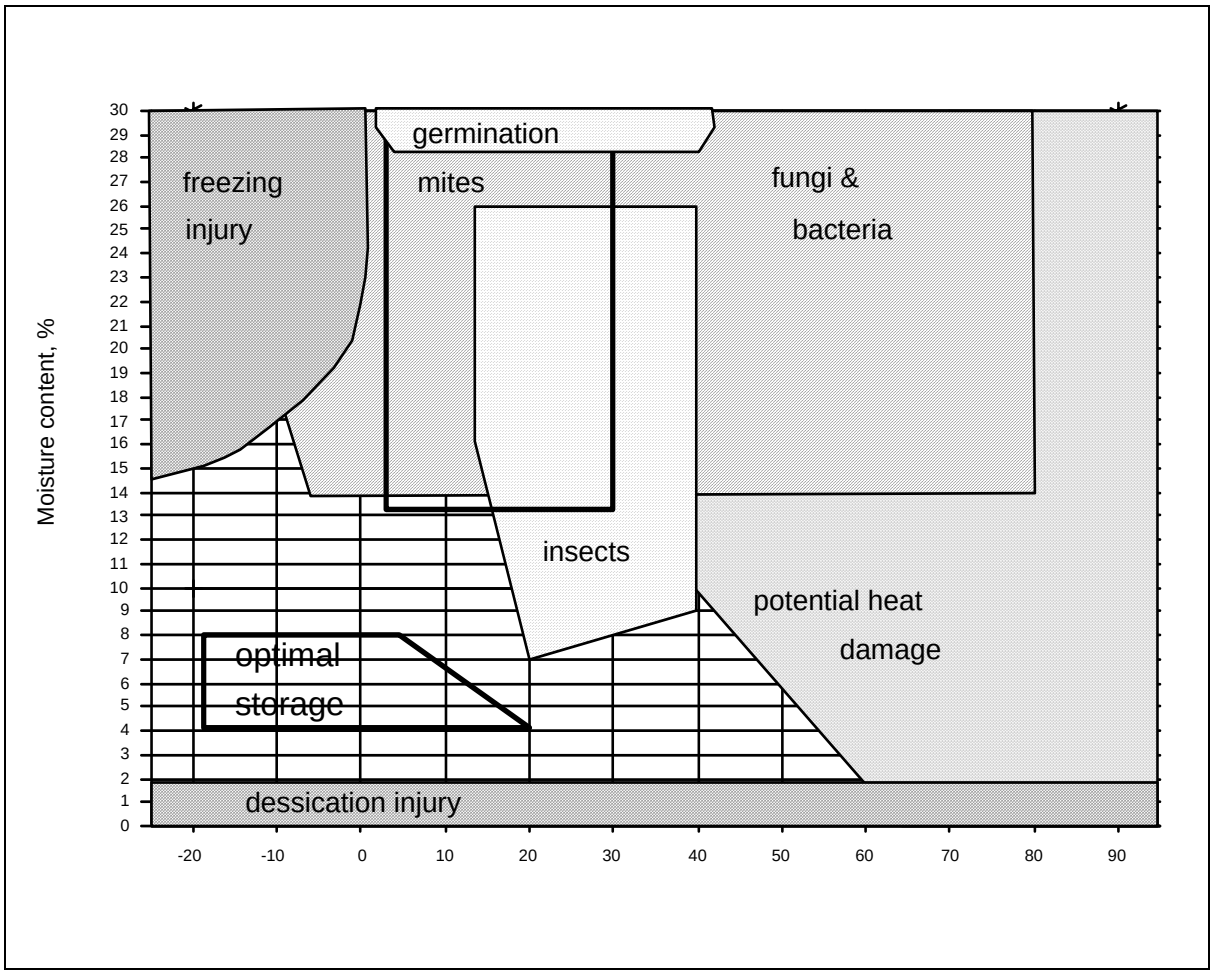

Figure 1: The relationship between seed moisture content and storage problems at different temperature for orthodox seed

3. MEASURING THE MOISTURE CONTENT OF SEED

When someone handles the same kind of seed many times, he may obtain a rough idea about its moisture content, but as storability of seed is greatly dependent on moisture content, it is important to be able to measure the moisture content accurately.

A seed is a living structure composed of complex substances such as carbohydrates, protein and oil, with some water in addition. In a moist seed the water will be present both as free water in the cells, and as water more or less hard bound in chemical compounds. Because of this it is in practice impossible to measure the amount of water exactly; the amount of water measured will depend on the measurement method and technique used. A standard method has therefore been adopted against which other methods are calibrated (that is: tables are made converting measurement results from the other methods to the standard method).

The standard method of measuring seed moisture content used by tree-seed producing units is defined in the rules of the International Seed Testing Association (ISTA) as the oven drying method, see 3.2. The most common other method used in tree seed production is quick moisture meters measuring the electrical properties of the seed, see 3.3.

According to the ISTA rules, moisture content of seed is expressed as the weight of water contained in the seed as a percentage of the total weight of the seed before drying (= fresh weight basis).

$$\%\, moisture\, content\, of\, seed = \frac{weight\, of\, water}{weight\, of\, sample\, before\, drying} * 100\%$$

3.1 Sampling

Sampling should be carried out in such a way that the moisture content of the sample is the same as the average moisture content of the whole seed lot. A sample is drawn from the seed lot by taking small portions at random from different positions in the seed lot and combining them. From this sample, smaller samples for moisture test are obtained by one or more stages. At each stage thorough mixing is followed either by progressive sub division or by drawing and combining small portions at random.

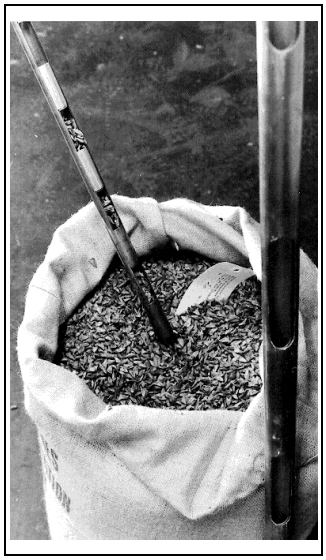

Figure 2: Seed stick triers

For seed lots in bags (or containers of similar capacity that are uniform in size) the following sampling intensity shall be regarded as the minimum requirement:

Up to 5 containers: Sample each container and always take at least five primary samples.

6-30 containers: Sample five containers or at least one in every three containers, whichever is the greater.

31-400 containers: Sample 10 containers or at least one in every five containers, whichever is the greater.

401 or more containers: Sample 80 containers or at least one in every seven containers, whichever is the greater.

Sampling from containers should if possible be done with a seed stick trier. If you have to do it by hand, take samples from different positions and depths in the container.

If you sample from seed during the drying process, for instance from seed on a tarpaulin in the sun, make sure that you have equal representation from the top and bottom layer on the tarpaulin at different locations.

The two samples for moisture testing are usually obtained from the original sample by progressive sub division by a soil or riffle divider.

DFSC Lecture Note C-8; Seed Testing, and the ISTA handbook describe sampling procedures in detail.

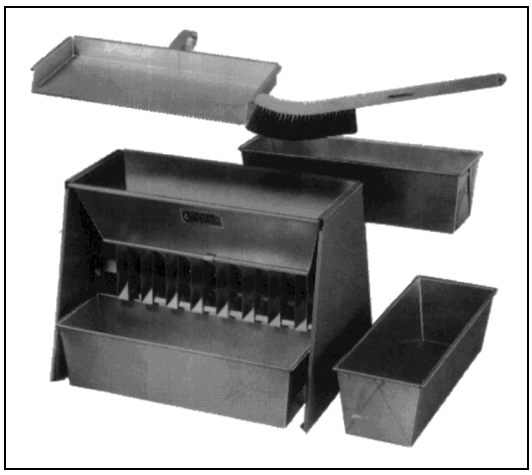

Figure 3: Riffle divider

To avoid changes in moisture content seed samples should be kept in moisture proof containers until the seed is tested.

Water may condense on seed taken directly out from a cold store or refrigerator just like on a cold drink coming directly from the refrigerator. Containers with seed taken out of a cold store or refrigerator should therefore be allowed to reach ambient temperature before they are opened.

3.2 ISTA Oven Drying Method

For the oven drying method ISTA prescribes the 'low constant temperature oven method'. Two independent samples, each of 4-10 g depending on container size, are tested. Not less than 30 seeds should be represented in each sample. The containers should be made of metal and have a lid.

Large seeds are cut into pieces and hard coated seeds ground in a grinding mill to ensure that the seeds are dried completely in the oven. One 4-10 g sample is then taken from the pieces or ground material and the other sample is cut or ground in the same way.

The two samples are dried in the two open containers in the oven for 17 ±1 hours (that is: between 16 and 18 hours) at a temperature of 103 ±1°C.

The balance used should have an accuracy of 0.001 g. At this accuracy, weighing is impossible if the containers are taken directly from the oven because hot air rising from the container creates an upward draught that makes the balance inaccurate. After drying the containers are therefore immediately closed and transferred to a desiccator with dry silica gel and allowed to cool before weighing.

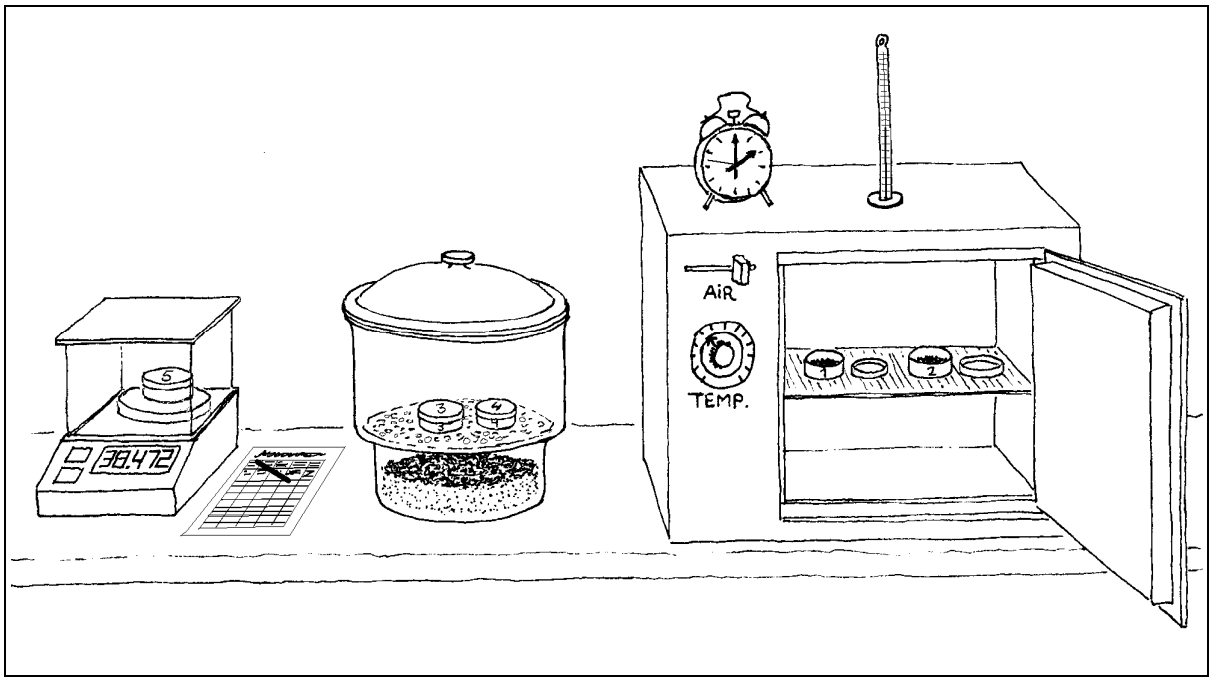

Figure 4: Analytical balance, desiccator and oven with two samples in containers

The weighing results are noted in a table as the one shown below. The moisture content on fresh weight basis is calculated as shown in the table and example. The result is stated as the mean of the two replicates, expressed with one decimal.

Seed lot no.	Replicate/ container no.	Weight of empty container gram	Weight of container+ seed Before drying gram	Weight of container + seed After drying gram	Moisture content % (fresh weight basis) A and B	Average
		M_1	M_2	M_3	$\frac{M_2-M_3}{M_2-M_1}*100\%$	$\frac{A+B}{2}\%$
	A	*8.721*	*12.793*	*12.507*	*7.024*	
	B	*8.357*	*12.338*	*12.043*	*7.410*	*7.2*
	A					

The results of the two samples of the same seed lot must not differ too much. The test should be repeated if the difference between the two results (A and B) is not within the tolerance limits given below. The reason for too big a difference is usually poor sampling. In the example above the difference between A and B is 0.386 % moisture content. If there are more than 5000 seeds per kg in this species, this difference is too big.

Number of seeds/kg	Moisture content		
	< 12 %	12-25 %	> 25 %
> 5000	0.3 %	0.5 %	0.5 %
< 5000	0.4 %	0.8 %	2.5 %

A more thorough description of determining moisture content by the ISTA oven method is given in the ISTA rules for seed testing and in DFSC Lecture Note no. C-8, Seed Testing,

3.3 Other Moisture Tests

The amount of water present in the seed can be measured in two ways: either by a **direct** method as the oven method described above where the water is removed and measured; or by **indirect** methods that quantify the effects of the water present in the seed.

The oven method gives a very accurate result but in practice you will not get the result until the next day. Seed-processing units therefore need immediate estimates of moisture content during processing. The most commonly used technique is quick moisture meters. Most of these are portable and battery operated.

Figure 5: DICKEY-john multi-grain portable moisture tester

Quick moisture meters come in a variety of makes. Nearly all measure the electrical properties of the seed. A fixed volume or weight of seed is poured into a measurement chamber and a reading is obtained. The reading is then converted through a table to the corresponding moisture content obtained if the seed had been tested by the oven method.

It is a time consuming task for a laboratory to make such conversion tables from the readings of the meter to results given by the oven method within the range of moisture contents one is interested in and for each species. Careful considerations on type and make therefore have to be made before a quick moisture meter is bought. DFSC Technical Note no. 47; Calibration of Moisture Meters describe the considerations and procedures in detail.

An example of a widely used quick moisture meter recommended by DFSC, the Dickey-john tri- or multi- grain Moisture Tester is shown in Figure 5.

Important points in relation to seed moisture content during seed procurement

Seed procurement step	Collection	Extraction/afterripening/drying	Storage
Seed moisture content (mc)	Indicator of seed maturity Indicator of storage physiology: if high mc at maturity, the seed may be recalcitrant if low mc at maturity, the seed is probably orthodox	The drying temperature that seeds tolerate depends on mc: the higher the mc the lower the temperature Mc of recalcitrant seed should be closely monitored	It is important to maintain: low mc in orthodox seed, high mc in recalcitrant seed
Methods to estimate or determine mc	Cutting test Oven determination	Field moisture meter Oven determination During drying, the field moisture meter is handy. Final mc should be determined in the oven	Oven determination (Field moisture meter) Oven determinations should be made routinely and can be supplemented with quick moisture meter determination

4. THE HUMIDITY OF AIR AND THE MOISTURE CONTENT OF SEED

The moisture content of most organic substances will adjust to the humidity of the air surrounding them: laundry will dry in the sun but become damp again if it is stored in a humid place, and wood will warp, expand and shrink according to changes in climate.

The same applies to seeds; they will dry or absorb moisture according to the relative humidity of the surrounding air.

4.1 The Relative Humidity of Air

The amount of water vapour that can be contained in a given volume of air is limited. The amount depends on temperature; the higher the temperature, the more water vapour can the air contain.

When the air contains the maximum amount of water vapour at a given temperature, it is said to be **saturated**. The amount of water that air will contain before it is saturated increases drastically with temperature.

If the temperature of air containing any amount of water vapour goes down, the air will sooner or later reach a point where it is saturated. If the temperature of the saturated air goes further down, some water vapour will condense. It is seen as water on the surface of cold things taken out of a refrigerator, or as mist or dew in the morning when the temperature has been low during the night.

How much the temperature can fall before saturation is reached depends on how much water is actually present in the air. If the air is very humid, the temperature can only fall a little before condensation starts. If the air is dry, the temperature has to fall further.

The amount of water vapour present in the air can be expressed in two ways: either as the amount that is actually present, which is called the **absolute humidity**, or as the amount present as a percentage of what could have been present at the actual temperature if the air was saturated; this is called the **relative humidity**.

The relative humidity of air is expressed as the amount of water vapour present as a percentage of the maximum amount of water vapour air can contain at the given temperature.

When air is saturated, the relative humidity is 100 %, and the so-called dew point is reached.
The relative humidity can be changed in two ways: **(A)** by changing the amount of water vapour in the air, **(B)** or by changing the temperature.

(A) if more water vapour is added to the air, the total amount present in the air will increase and get closer to the amount possible in saturated air. In this case both the absolute and the relative humidity will increase;

(B) if temperature is raised, a larger amount of water vapour can be present before the air is saturated, and the difference between the actual amount present and the amount present at saturation will increase. If temperature is raised, the relative humidity will fall even though the absolute humidity remains the same.

Seed will dry or absorb water until its moisture content is in balance with the relative humidity of the surrounding air. This moisture content is called the equilibrium moisture content. The relative humidity where the moisture content of the seed is in balance is called the equilibrium relative humidity.

It is thus not possible to dry seed down to a moisture content lower than the equilibrium moisture content at a given temperature. Whether you will be able to dry your seeds down to a required moisture content therefore depends on the temperature, and thereby the relative humidity, of the air where you dry the seed.

4.2 Sorption Isotherms

When the relationship between different relative humidities of the air around the seed and the equilibrium moisture content the seed will reach is known, a graph called sorption isotherm can be made.

Sorption isotherms indicating equilibrium moisture contents at different conditions can for instance be used to estimate to which moisture content seed can be dried in a given climate; but the points A-C below should be kept in mind when using the sorption isotherms as drying curves.

An example of a sorption isotherm is shown in Figure 6. Here the curve indicates which moisture content moist wheat will dry down to if kept at different relative humidities at 35°C.

Example 1:

When moist wheat is placed at 35°C and 40% relative humidity, and the air is constantly renewed so that the relative humidity stays at 40%, then the moisture content of the wheat will drop to an equilibrium moisture content of 9.8%.

The speed of absorption or desorption depends on temperature, speed of airflow, how permeable the seed coat is, relative humidity of the air, and moisture content of the seed. The time needed to reach equilibrium may be anywhere between 1 day and 3 weeks.

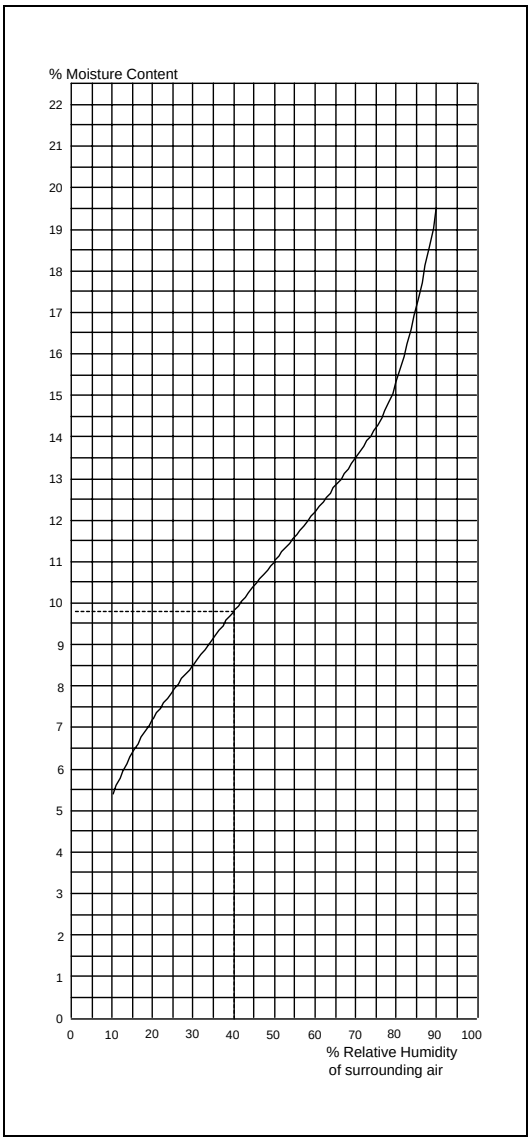

Figure 6: Equilibrium moisture content of wheat at 35°C.

The curve indicating equilibrium moisture content,

will not always be identical. It will vary: depending on **(A)** species, **(B)** temperature and **(C)** it will also vary slightly depending on whether the seed is drying or absorbing moisture from the surrounding air:

(A) Seeds consist of carbohydrates (e.g. starch), proteins and oils, but practically only carbohydrates and proteins can absorb water.

The curve indicating equilibrium moisture content of seeds with a high oil content will therefore be lower than a curve for seed with low oil content.

(B) A rise in temperature will increase the speed of vibration of the water molecules. They will therefore be more liable to evaporate and the seed will find equilibrium at a lower moisture content at higher temperatures. In practice the curves are approximately 1% moisture content lower per 10°C rise in temperature.

(C) If the relative humidity around a seed at equilibrium moisture content is raised, then there has to be a certain difference between the relative humidity and the seeds equilibrium relative humidity before the seed starts absorbing moisture.

At a given relative humidity absorption curves are 1-2% lower than desorption curves.

In Figure 7 and Appendix 1 some general sorption isotherms based on data from various sources are given.

To estimate moisture content with a hair hygrometer as a field method can only be done with reasonable accuracy if sorption isotherms for the commonly used species are established. This is done by measuring the moisture content of seeds at equilibrium with known relative humidities.

DFSC would be very interested in receiving copies of sorption isotherms of tropical tree species.

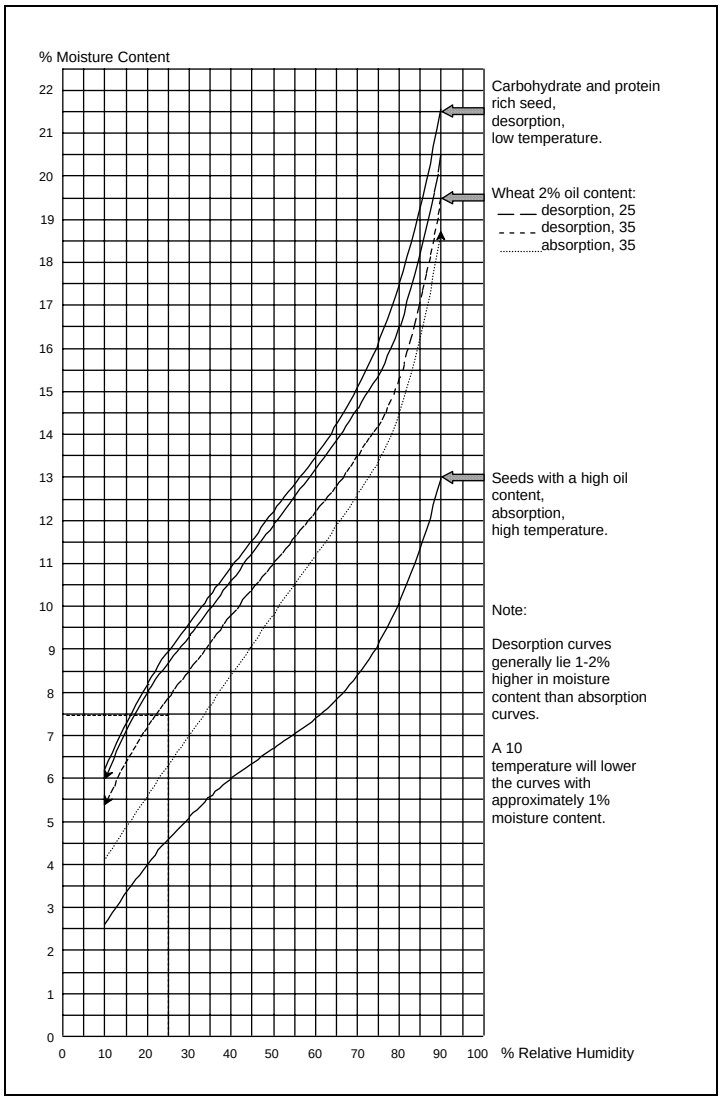

Figure 7: Sorption isotherms.
Moisture content (% wet weight) in equilibrium with relative humidities (extracted from Roberts 1972).

4.3 Measuring Relative Humidity

There are various instruments for measuring relative humidity: 1) psychrometers and, 2) hair hygrometers, and 3) electronic hygrometers where a sensor changes electrical properties according to how much moisture it can absorb from the air. Electronic hygrometers are usually rather expensive if they are accurate at low relative humidities (5-15% relative humidity).

A psychrometer consists of two thermometers next to each other. The bulb of one of them is kept moist inside a thin cotton wick placed like a stocking around the bulb with the other end dipped in a container with water, so that the surface of the bulb is kept wet by the wick. The other thermometer should be kept dry, and both thermometers should be placed so that the air has free access.

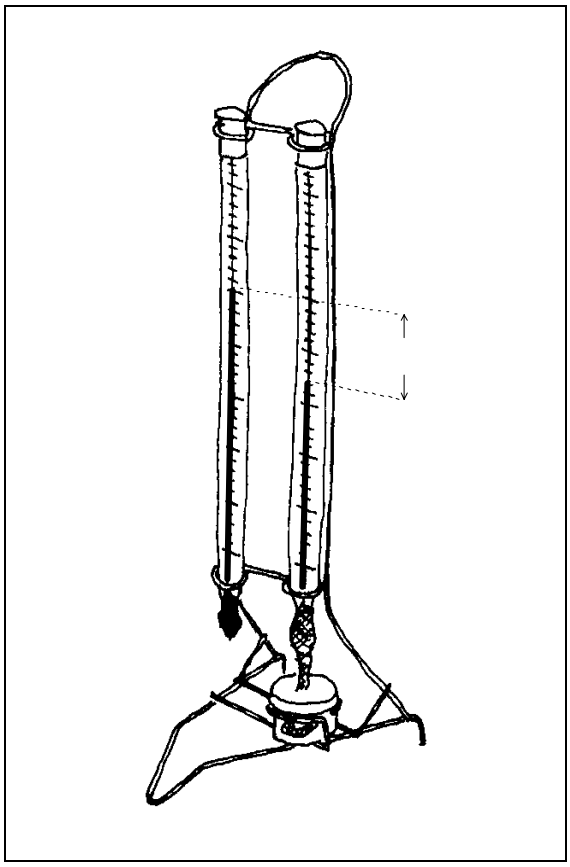

Figure 8: A psychrometer.

Water will evaporate from the wet bulb until relative humidity on the surface of the wick is 100%. Energy is consumed for the evaporation, and as no energy is supplied from outside, the temperature of the wet bulb will fall compared to the dry bulb. The drier the air (the lower the relative humidity of the air), the more water will evaporate and thus the larger the temperature difference between the two bulbs.

The psychrometer is usually delivered with a table of wet and dry bulb temperatures and corresponding relative humidities. DFSC Lecture Note C-5, Seed Moisture and Drying Principle, describes how to use two thermometers as a psychrometer.

Hairs (in hygrometers usually human or horse) contract when dried. One end of the hairs inside the hygrometer is connected to a fixed point in the instrument, the other end is connected to a spring loaded needle on a scale showing the relative humidity. When the hairs dry and contract, they pull the needle down towards 0% relative humidity

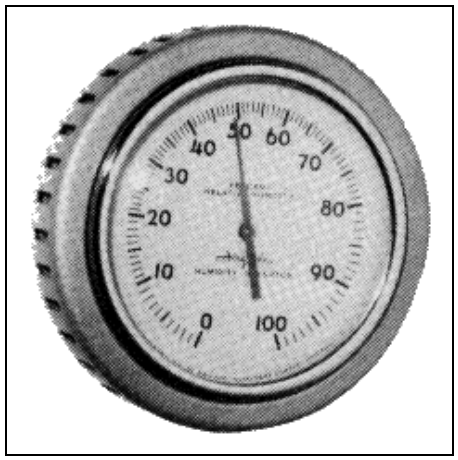

Figure 9: Hair hygrometer

For more details see DFSC Lecture Note C-5. Also check the manual that came with the hair hygrometer to see maintenance procedures.

Hair hygrometers are usually accurate to within 5-10 % relative humidity in the range 15-95 % relative humidity.

5. SEED DRYING

5.1 Principles of Seed Drying

Normally, all fruits have a variable but high moisture content at full ripeness. Under normal conditions, orthodox species will mature during the dry season allowing the local weather to dry the fruits and seeds. Indigenous recalcitrant species on the other hand very often mature during a moist season to prevent the seed from drying out and to allow it to germinate before a dry season.

Examples of seed drying will be given in the following. There are no differences in the procedures for drying fruits and seeds, except for the fact that fruits are usually more bulky than seeds.

Fully ripe orthodox seed usually stores best if dried down to 6-8% moisture content. This is in many cases lower than the moisture content the seed would reach in nature. To reach this low moisture content you will have to create a sufficiently low relative humidity in the air surrounding the seed. When moisture evaporating from the seed raises both the absolute and the relative humidity around the seeds, the air will have to be changed with new air with a sufficiently low relative humidity, for instance by the wind.

The speed of drying is determined by: (A) speed with which moisture can migrate to the surface of the seed for evaporation, (B) air velocity around the seed, (C) temperature, and (D) relative humidity.

(A) **The speed with which moisture can migrate to the surface of the seed for evaporation:** in practice the density and thickness of the seed coat often determine how fast moisture can migrate to the surface of the seed.

On the other hand, if the seed coat is porous and the surface of the seeds dries faster than moisture can migrate out through the seed, the outer layers of the seed may dry out and perhaps collapse trapping moisture inside the seed. This will prevent any further drying and may present a risk to the viability. Immature fruits, for instance green cones that have not turned sufficiently brown, may prevent drying by 'case hardening' of the outer layers. In these cases the only option is to re-moisten the seeds or fruits, let them complete the ripening process and repair damages inflicted by the collapse of tissue in a cool environment, and then repeat the drying process at a lower rate.

(B) **Air velocity:** drying time is approximately halved when the velocity of the air around each seed is doubled. The upper limits to air velocity are the speed of available fans (or the velocity of natural wind), practical limits to how thin the layer of seed can be, and the point when the air starts moving the seed.

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

Note that the maximum temperature that seeds will tolerate depends on species and how dry the seed is. Until specific temperature for your species have been established, **safe drying temperature for most orthodox species is 35°C until the moisture content is below 15%. Below 15% moisture content the temperature can be raised to 45°C.**

The air temperature that seeds can tolerate also depends on rate of drying since evaporation cools the seed and, if energy input is kept constant, temperature of the seeds themselves will be lower than air temperature (like the wet bulb of the psychrometer on page 12).

In this connection you should note that a high temperature also increases respiration and ageing process. This implies that the period during which the seed is subjected to a high temperature should be kept as short as possible, by keeping the relative humidity as low as possible by ensuring sufficient ventilation.

(D) **Differences in relative humidity:** relative humidity of the air should during the whole process be lower than equilibrium relative humidity corresponding to the moisture content of the seeds at that stage of the drying process. The equilibrium relative humidity can be found from the sorption isotherms (see Figure 7 and Appendix 1).

The speed of drying will be high if the relative humidity of the drying air is low compared to the equilibrium relative humidity as each unit of air can carry away more water. If for instance the same relative humidity and temperature are maintained during the drying process, the speed of drying will decrease as the seed moisture content is reduced.

It is important that seed is sufficiently dry before storing. A lot of seed is stored with too high moisture content. Reduction in viability (and loss of total value) when the seed is stored at a high moisture content should be compared to the cost of drying plus the smaller reduction in viability when the seed is stored at a lower moisture content.

Example 2:

cost of procuring 1 kg seed at 10% moisture content	300 $
cost of additional drying to 6% moisture content	20 $

If stored for 1.5 years at 10% moisture content, there may be a 30% reduction from 100% germination to 70% germination,

that is a loss of $\frac{30}{100} * 300\$ =$ 90 $

If stored for the same 1.5 years at 6% moisture content, there may only be a 5% reduction from 100% germination to 95% germination,

that is a loss of $\frac{5}{100} * 300\$ + 20\$$ for additional drying = 35 $

The loss in value when stored for 1.5 years would in this case be reduced from 90$ to 35$ per kilo by drying from 10% moisture content to 6% moisture content before storage.

The time needed for drying can be estimated from local experience but a routine check on moisture content before storage is necessary, see chapter 3.

5.2 Drying in the Shade

Drying in the shade can be advantageous under some circumstances:

High temperatures in the sun can damage seeds with high moisture content.

Seed cannot after-ripen and repair small mechanical damages once moisture content is lower than 15-20%. If the seed is not fully ripe, a slow drying process will permit it to complete the ripening processes.

Recalcitrant seed need careful adjustment of moisture content. It is very difficult to lower moisture content of seeds of a recalcitrant species from 60 to 45 % in the sun without drying some of the seeds too much. This process is much easier to control if the seeds are placed well ventilated in the shade.

There must be adequate ventilation when seed is dried in the shade as high relative humidity will promote fungus and insect attack. Well ventilated covered walkways or open sheds where driving rain cannot enter are normally used for drying and afterripening seed or fruit in gunny bags.

A more sophisticated arrangement for drying in the shade consists of a well-ventilated room and stacks of shelves with trays with wire mesh bottom. The fruits are spread in a thin layer in the trays and stirred regularly. This arrangement is also useful for seed of species which can easily be damaged by heating in the sun or kilns, and for species which need to be stored at relatively high moisture content in order to retain viability. See also DFSC Lecture Note C-6 on seed handling prior to processing.

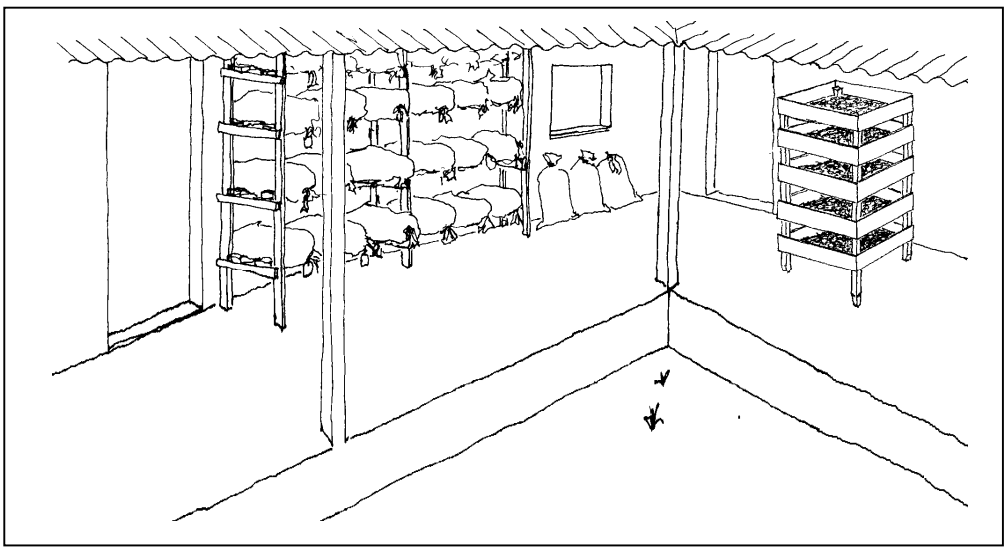

Figure 10: Cones in gunny bags and seed on netting trays in a covered walkway

5.3 Drying in the Sun

The sun raises the temperature, thus lowering the relative humidity in the air around the seed. It is necessary to ensure a continuous and adequate air flow to remove the evaporated moisture in the air around the surface of the seed.

The moisture content of the seed will come to rest at an equilibrium moisture content corresponding to somewhere between the day and night relative humidity around the seed.

The essentials in sun drying are:

(1) To avoid shade and ensure as many hours as possible in the sun.

(2) To allow free access of the wind to a thin layer of seed (if necessary, erect a mobile windbreak to prevent the seed from blowing away on windy days rather than having an inefficient drying area on calm days).

(3) To prevent the seed from absorbing moisture during the night or when the relative humidity is high. Cover the seed with a tarpaulin against dew, rain and humid air flow, and store indoors or in airtight containers when the moisture content of the seed is so low that absorption cannot be prevented during hours without sun.

(4) To prevent overheating while the seed still has high moisture content. If the moisture content of the seed is high, initiate drying in the shade and transfer the seed to the sun when the moisture content is below 15%. High temperature and moisture content together accelerate respiration and impose stress to the seed; see also safe drying temperatures on page 14.

(5) To remove any seeds which have separated from fruits and cones during drying in order to prevent unnecessary exposure of the seeds to high temperatures.

In the tropics nearly all seed is dried in the sun. Either in flat baskets or trays, or on concrete decks or tarpaulins. Under most conditions this is the most convenient and cheapest form of drying.

The actual temperature reached during sun drying depends on many factors and varies from day to day and during the day. The temperature can be monitored by placing a thermometer just under the surface of the seeds or fruits so that the sun does not reach the bulb.

In the dry season, most sun-dried seed will reach a moisture content of 7-10 % depending on climate. A moisture content of below 8% is under many circumstances sufficiently low for short-term storage at ambient temperatures, and also sufficient for medium-term storage at below 5°C.

If your climate is very humid, and you generally have problems in drying your seed down to below 8 % moisture content by drying in the sun in a couple of days, you will have to use more sophisticated methods of drying such as drying under transparent covers or kiln drying. A review of the possibilities and methods is found in DFSC Lecture Note C-5, Seed Moisture and Drying Principles.

Example 3:

A batch of seed gets 4 hours of direct sunlight a day raising the temperature to 40°C, the average seed temperature the rest of the day and night is 22°C, and the average dew-point temperature is 18°C.

The relative humidity in the sun will be 28% and the rest of the day and night approximately 78%.

The seed will normally not come down to the equilibrium moisture content corresponding to 28% relative humidity during the 4 hours in the sun and will certainly absorb moisture again during the night. The moisture content in the end will be somewhere between the equilibrium moisture contents corresponding to 28% and 78% relative humidity, depending on how good ventilation is during high-temperature hours and how effectively ventilation is shut off during low-temperature hours once the seed has a moisture content lower than the equilibrium moisture content to 78% relative humidity.

From the sorption isotherms in Appendix 1 and in Figure 7 we can see that the equilibrium moisture content to 28 % relative humidity at 40°C is just below 8% moisture content. If we want the seed to reach 8% moisture content, we will therefore have to ensure the seed as many hours in the sun as possible and put the seed in containers or wrap them in a tarpaulin during the night (see Appendix 3).

6. MAINTAINING MOISTURE CONTENT DURING STORAGE

6.1 Containers for Orthodox Seed

The objective will be to keep the seed dry and protected from pests. This can be done by placing the seed in impermeable containers if the seed is dry enough to prevent fungal growth.

The outer container should normally be rigid and of a handable size fitting the sizes of the seed lots; i.e. plastic or metal boxes, plastic or metal cans from 1 to 30 litres, and for large seed lots plastic drums of 60 to 150 litres.

If the seed is sealed in impermeable plastic bags (thick laminated plastic bags) inside the container, there is no special requirement to the sealing of the outer container. If the seeds lie loose, or in ordinary plastic bags (of low density polythene, LDPE, which is permeable to water vapour) in the container, the seal or gasket of the container should be able to hold vacuum in order to prevent water uptake. This will normally only be possible with glass jars with rubber seal for preserves, jerrycans (plastic or metal tins for petrol) and the common blue plastic barrels with black lid and clamp-ring closing, and then only if the seal is not defective. The necessity of impermeable sealing against water vapour increases with the length of storage time.

The relative humidity inside the store is normally higher than the equilibrium relative humidity to the moisture content of the seed. If the store is cooled (for instance with an air conditioning unit), the difference in relative humidity will be high. Typically, the relative humidity in a cold store at 4°C is above 90% RH. The equilibrium relative humidity to seed at 6% moisture content

is approximately 15% RH. During storage at ambient conditions the differences in relative humidity are lower, but the higher temperature accelerates water-vapour transmission through plastic materials.

Seed with 6% moisture content stored in sealed plastic bags of reasonable thickness without outer container can be expected to gain approximately 0.3% moisture content in a year if stored in a cold store (4°C, 95%), and to gain 3% moisture content in a year if stored at ambient conditions (25°C, 80%RH). Therefore storage of dry seed in plastic bags without an impermeable outer container is not recommended for more than relatively short periods.

Plastic bags should be sealed with a heat sealing. Tying the bag with a string may facilitate reopening, but the chance of water uptake and loss of seed will increase.

6.2 Containers for Recalcitrant Seed

Recalcitrant seeds respire actively and will suffocate in closed containers. They must be stored in relatively thin layers in open containers which allow plenty of air exchange. It is therefore difficult to maintain the moisture content of the seeds and water should be added frequently by spraying and mixing the seeds.

7. SELECTED REFERENCES

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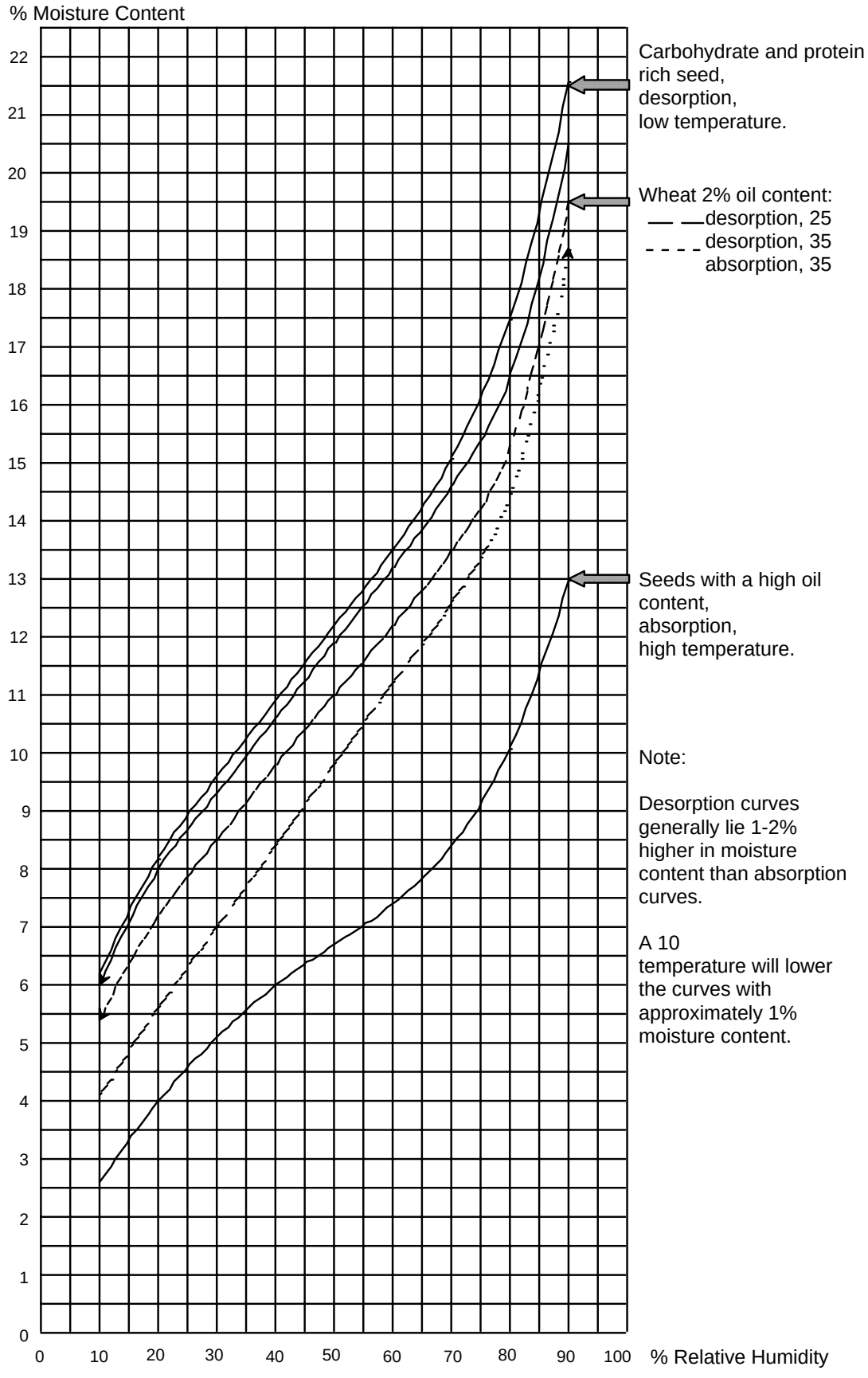
SORPTION ISOTHERMS

Moisture content (% wet weight) in equilibrium with relative humidities (extracted from Roberts 1972).



The tarpaulin method of sun drying pine cones and seed extraction

Summary of DFSC Technical Note no. 9, 1984.

The method has been extensively used in Honduras for *Pinus oocarpa* and *P. caribaea.* It has also been used in other countries and for other species such as *Acacia* and *Eucalyptus*.

The tarpaulins must be strong enough to resist handling, puncturing or tearing, and should minimise condensation, for which reasons heavy-weight waterproof canvas is preferred rather than plastic-coated cloth or polythene sheets. A size of 5x7 m to 5x10 m is suitable to be handled by 2-3 people. Wider sheets than 5 m will be inaccessible without walking on the tarpaulin. Smaller sizes can be used where many small lots should be kept separate. The capacity of a tarpaulin is approx. 100 litres of closed cones per 3 square metre (in a layer one cone thick with 30 cm free edge).

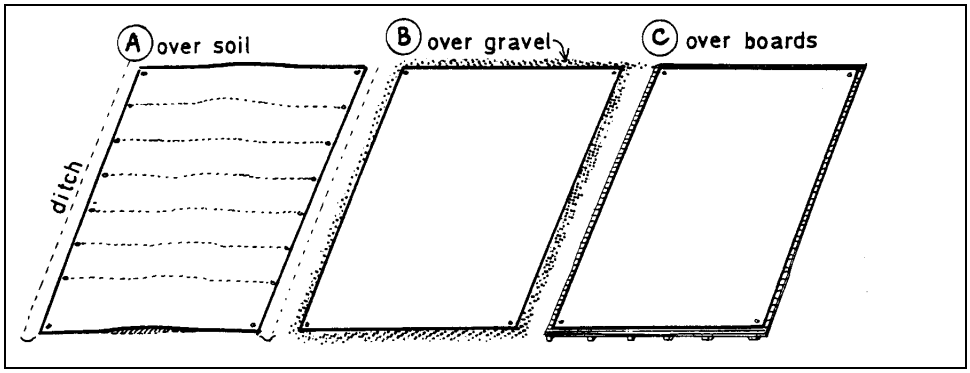
The time required to fully open ripe cones depends on species and weather conditions, generally it should be possible in 2-3 days during the dry season with good weather.

The tarpaulins should be laid out on an area free from shade the whole day, but sufficiently sheltered from the wind to avoid the seed blowing away. The ground should be flat, well drained and free from sharp projections that could puncture the tarpaulin. A strip of the ground one third of the tarpaulins width down the middle will be permanently covered and should be well drained. Drainage can be obtained by placing the tarpaulin on sloping ground and:

A) On compacted impermeable soil, making a shallow drainage ditch around the perimeter of the tarpaulin, and using the material for a shallow mound under the centre third strip of the tarpaulin.

B) Laying out a 10 cm thick layer of coarse gravel. Provided the stones are max. 1-2 cm in diameter and rounded as from a river bed - not chippings.

C) In waterlogged areas, try to find somewhere else, or make a raised wooden platform, ensuring that the joints are as level as possible.



Dense grass covers in pastures and concrete patios can be used if they have adequate slope for surface run-off. Pine needles can also be used to raise the tarpaulin from the ground.

It is essential to keep the tarpaulins in good condition. Clean them regularly with a brush and washing, check the impermeability of the fabric and treat when necessary. If a cone lot becomes infected with fungi, treat both sides of the tarpaulin with fungicide. Make sure all stitchings, tears and punctures are properly repaired in time.

APPENDIX 2

Extraction

1) The mature cones are spread out over the tarpaulin using a rake which has a spacing of the tines smaller than the closed cones.

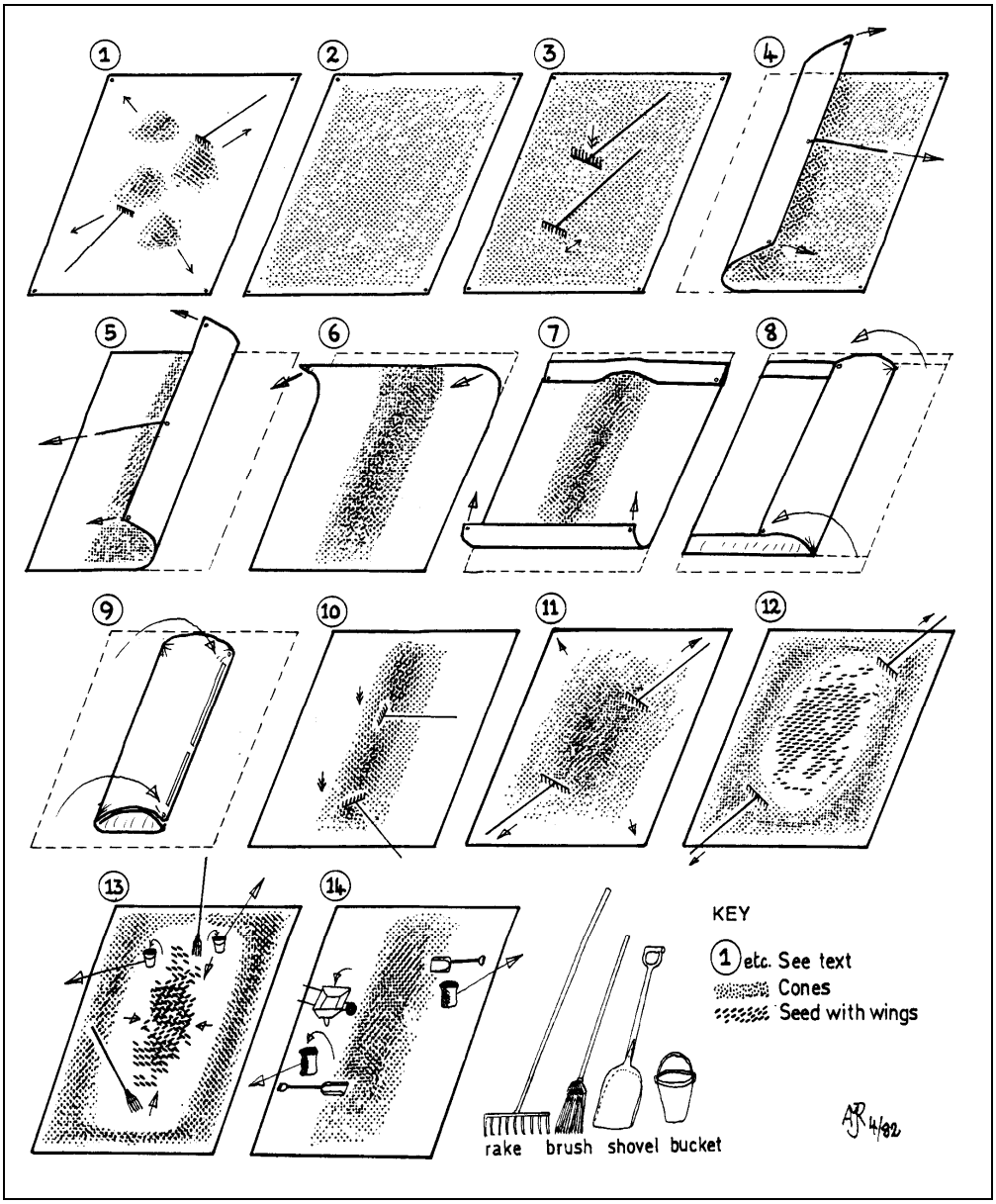
2) To avoid spillage, the cones should only be raked to within 30 cm of the edge of the tarpaulin.

3) During the day, the cones should be agitated as often as possible (say every 2-3 hours) using the back of the rake lightly knocking the cones and raking back and forth. Note that the more often the cones are moved, the more efficient is seed extraction.

4-9) At the end of the day (about 1 ½ hours before sunset) or whenever it is going to rain, the cones are gathered up and covered as shown. The last side to cover the cones (9) should be the one facing the prevailing wind. Weights should be placed along the free edge to avoid lifting by wind and entry of rain.

10-12) It is best to remove seeds that have been extracted at the beginning of each day when uncovering the pile. (10) Tap the pile with the back of the rake to ensure that the seed falls down through the pile. (11-12) Gently rake the cones to the perimeter of the tarpaulin lifting more than dragging them. (13) The exposed seed are brushed together and removed.

If drying is to be continued, the cones can be raked back over the tarpaulin. If it is required to remove some seeds later in the day, the cones are thrown into the middle of the tarpaulin as shown in (4-7) and the procedure above is followed.



Remember that the cones must be ripe before drying.

Do not allow water to enter the tarpaulin through incorrect folds or punctures. The water will settle in the bottom with the seed and provide ideal conditions for germination.

To minimize damage to the seed and dirt on the tarpaulin do not walk over the cones.

Try to ensure that the tarpaulin is open whenever the drying conditions are positive.

APPENDIX 3

Minimum moisture content for some recalcitrant and intermediate seeds

Species	Minimum moisture content, % wet weight
Auraucaria angustifolia	37
A. araucana	38
A. scopulorum	12
A. nemorosa	12
A. rulei	12
A. columnaris	12
Dipterocarpus obtusifolis	45
D. turbinatus	45
D. intricatus	10
D. tuberculatus	12
D. alatus	17
Shorea robusta	40
S. roxburghii	35
S. almon	40
Theobroma cacao	33-35

Sources:

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2: P. B. Tompsett, 1987. Desiccation and storage studies on *Dipterocarpus* seeds. Ann. Appl. Biol. 110, 371-379.

3: P.B. Tompsett, 1985. The influence of moisture content and storage temperature on the viability of *Shorea almon*, *Shorea robusta* and *Shorea roxburghii* seed. Can. J. For. Res. Vol 15, 1074-1079.

4: Y.L.Hor, H.F.Chin and Mohd. Zain Karim, 1984. The effect of seed moisture and storage temperature on the storability of cocoa (*Theobroma cacao*) seeds. Seed Sci. & Technol. 12, 415-420.