LiveSeeding

PRACTICAL GUIDE

for drying and storing vegetable seeds

in organic small-scale and on-farm seed production

Co-funded by the European Union

Funded by the European Union, the Swiss State Secretariat for Education, Research and Innovation (SERI contract number 22.0412) and UK Research and Innovation (UKRI). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA, nor SERI or UKRI.

UK Research and Innovation

Cite as: Gudinchet M, Klaedtke S, Groot S, Practical Guide for drying and storing vegetable seeds in organic small-scale and on-farm seed production, LiveSeeding project, 2023, 40 p (version: February 2024)

Published: February 2024

Permalink: https://orgprints.org/id/eprint/52128/

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The editors would like to express their sincere thanks to Steven Groot, who inspired the writing of this guide and coined the phrase "Don't waste your effort!".

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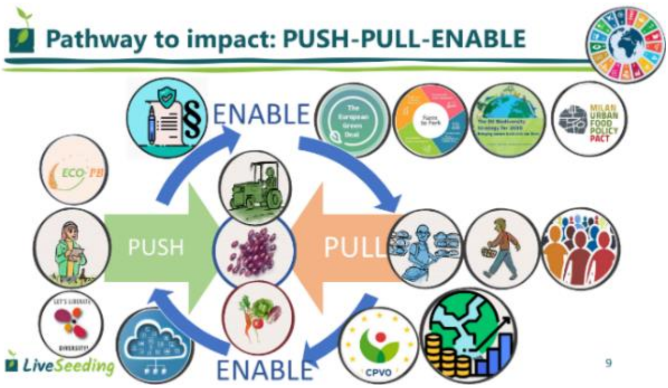
1. Project summary

LiveSeeding - Organic seed and plant breeding to accelerate sustainable and diverse food systems in Europe *is a 4-year Innovation Action funded by the European Union, the Swiss State Secretariat for Education, Research and Innovation (SERI) and UK Research and Innovation (UKRI).* The project started in October 2022 and brings together 37 organisations operating in 15 European countries. LiveSeeding provides science-based evidence and best practice solutions to help achieve 100 % organic seed.

LiveSeeding contributes to the transition towards environmentally-friendly, climate-neutral, healthy and fair food systems through a PUSH-PULL-ENABLE strategy to

- enhance the availability and adequacy of organic seeds of cultivars appropriate to organic farming (PUSH),
- increase and stabilise the market demand for organic seeds of cultivars appropriate to organic farming (PULL),
- foster an enabling policy and regulatory environment where both demand and supply can harmoniously and productively negotiate without irrelevant constraints due to legal restrictions and/or regulatory fragmentation (ENABLE).



LiveSeeding addresses the topics in a holistic multi-actor, multi-stakeholder, participatory approach involving stakeholders along the value chain in 17 local Living Labs (LLs) and 3 established networks of organic breeders (ECO-PB), seed savers (ECLLD) and Milan Urban Food Policy Pact (MUFPP). 15 European countries cover the different pedoclimatic zones and socio-economic contexts, including countries with a low level of development in organic seed and breeding in East and South Europe.

2. Booklet summary

The germination rate and vigour of seeds affect how well a crop emerges and establishes. They are a crucial aspect of seed quality, as poor seed vigour will result in seedlings that are more sensitive to abiotic stress (for example soil compaction or drought) and biotic stress (pathogens, especially soil-borne ones) and might even affect the final performance of the crop!

During seed storage, seeds age and their quality declines by oxidation. This is influenced by seed moisture level, presence of oxygen, and temperature, in decreasing order of importance. This guide-booklet explains and highlights the main issues to look out for when drying and storing seed. It proposes cost- and time-saving solutions for on-farm drying and storage, namely:

- How to dry the seeds efficiently
- How to ensure they stay dry during storage
- How to protect them from oxygen

The fact that seeds must be properly dried after harvesting and stored in a dry, cool and dark environment is known to many seed producers. Yet, experience shows that these obvious precautions are not always taken, due to lack of time and resources or because of organisational difficulties. By providing practical examples, cases and guidance to reflect on your own context and objectives, we hope this booklet will help to lift some of the practical challenges associated with the drying and storing of vegetable seeds in small-scale seed enterprises and on-farm.

Don’t waste your efforts!

Once you have spent time and resources to produce good seeds, ensure they are stored in the best possible conditions, so you and the world may benefit from it as long as possible!

3. Objectives

It is important to consider your seed conservation objectives, according to context, crop species, and the diversity and quantity of seed produced, as well as the final use. Before working out your own objectives for seed drying and storage, here are 3 example cases, representing a range of contexts and possible objectives.

Example 1: Josette selects and harvests seeds of 10 varieties of tomatoes for an amateur exchange network.

To extract the seed, she ferments them at room temperature for about 24 hours (or as appropriate according to temperature), then cleans and dries them on a drying shelf composed of several drying racks (handmade without heating or ventilation) on kitchen towels for a few days.
They are then packaged separately by variety, in 150 ml glass jars, and bagged in paper envelopes on demand during the winter to be mailed to other members of the informal exchange network.

Each year in January, Josette does germination tests on blotting paper in her kitchen, with 25 seeds per variety. When the germination rate drops below 85%, Josette decides to grow the variety again that year. After harvesting the new seed lots, she throws or gives away the old seed stock.

In the given context, the storage conditions are sufficient to preserve and distribute the tomato cultivars in the amateur seed network: the germination capacity remains high for several years. Users do not encounter problems, as they transplant their seedlings manually. As seed-saving is a volunteer activity and Josette doesn't earn money with it, she does not have a loss of income related to the discarded stock.

⇒ Objective: As long as Josette is satisfied with the frequency at which she has to grow out each variety to renew the seed stock and she does not want to add additional cultivars to her collection, there is no need to put resources and effort into improving her seed quality and storage conditions. If her network is satisfied with the quality of the seed she provides, she can probably continue as she has been doing.

Example 2: Bohuslav propagates onions and carrots for a regional farmers' seed network.

Bohuslav took over his parents' organic farm in a mid-mountain region traditionally devoted to cattle breeding and grazing. On the top of herding 40 cows, he grows a few hectares of buckwheat and broad beans. He also does some market gardening, on a small scale, for his own consumption and for farm gate sales.

He participates in a regional farmers' seed network. The farmers choose the varieties they find best adapted to their region, allocate the multiplications among the group and share the seed produced. The selection is carried out in a participatory way, with field visits to select the plants to harvest the seed from.

Bohuslav usually propagates onions and carrots. In the first year, he selects about 300 plants of each in the field where he produces vegetables. They are overwintered in his cellar and replanted in the spring of the second year to flower and bear seed on a small patch near the bee hives.

As he plants a lot of plants for seed production, he harvests more than enough seed for the network. The germination of the carrot seeds remains sufficient for a few years, but the onion seeds only_have satisfactory germination for two years of storage at the most, which means that regular multiplication is necessary.

This is a problem because in order to avoid cross-breeding only one variety can be multiplied per year, while the farmers in the valley work with four varieties of onions. If Bohuslav was able to increase the shelf life of the onion seed to 6 years, he would not have to throw away the remaining stock after two years and could optimise his rotations.

⇒ Objective: To achieve a good storage of onion seeds over 6 years, using 2kg per year, distributed among 6 farmers.

Example 3: SuperSeed is a non-profit seed enterprise that selects, maintains, and multiplies organic seeds of traditional local varieties under artisanal, low-input conditions.

Seeds are sold mainly to home gardeners via a web-shop, but also to some small-to-medium scale market gardens in the region. These market gardens cover community-supported agriculture structures, as well as family farms, including both organic and conventional farming.

Clients either sow the seed directly or seedlings are produced by a plant nursery in the region. This plant nursery agrees to work with small seed batches, but needs the germination to be high, homogenous, and reliable.

Some of the seed batches are sold over a rather long period of time and stocks are progressively drawn from over several years to be packed for shipping. In some cases, the stocks are accessed often, and at irregular time intervals.

Each winter, all batches are tested for germination, and if germination does not meet the minimum requirements for the given crop species, respective batches are discarded or donated to schools in the region.

⇒ Objective: Optimal storage conditions for the entire stock in order to increase the shelf life and the time to market each seed batch.

Your turn: Set your objectives!

Based on the three examples, now set your own conservation improvement targets for each of the species and varieties you produce.

You can use the table in the appendix for this: ***Sheet 1***

4. Background Information & Guidelines

For a better understanding of the stakes of seed drying and storage, we will now have a closer look at the underlying processes, pointing to key aspects and means of action. This understanding will enable you to devise your own action plan to optimise your own seed drying and storage practices, based on the objectives you set in the previous section.

4.1. Harvest and temporary storage

This booklet does not focus on the growing conditions and harvest of the seed crop. The basic rules for harvest are:

- ⇒ Seeds are harvested as close as possible to full maturity. It is at this point of development that they will have the best physiological resources for protection and conservation.
- ⇒ Dry-seeded crops should be harvested when seeds start to dissociate from the mother plant. It is often necessary to harvest plants or plant parts, leave them to dry further and thresh them later, especially for seed crops that mature gradually and shatter. Harvested material should be dry, but not too dry to avoid shattering and seeds breaking (especially when using a combine harvester for pulses).
- ⇒ The fruit of wet-seeded crops should be at full maturity before processing (extraction, sometimes fermentation). For pumpkins and other winter squash, it is recommended to store the fruit for several weeks to months before seed extraction.

The following assumes that the seeds were mature and dry enough at harvest, a pre-requisite for good quality.

Plant material that has been harvested to be dried and threshed later should be placed in the best possible conditions regarding humidity and temperature. However, often there is little choice and bulky plant material is left in an empty greenhouse or barn. There is a risk of too much heat, direct sun, humidity, and pests. It is therefore essential that threshing takes place as soon as possible once the plant material has dried and the seed fully matured.

If thorough seed sorting and cleaning is not possible right away, you may consider rapid and rough pre-cleaning, followed by further drying to preserve the seed under optimal conditions while waiting for the final sorting and cleaning step.

4.2. Seed ageing

Like any living being, seeds age. At the end of the ageing process, the seeds die and will not germinate anymore. Before that, seeds gradually accumulate damage, mainly due to oxidation. When seeds are sown, take up water and reactivate their metabolism, they must repair the accumulated damage before germinating. This takes time and energy, leading to slower germination and more heterogeneous emergence. If too much damage was accumulated, repair is no longer possible and seeds won't germinate at all.

Oxidation and seed ageing are driven by three main factors, in the following order of importance:

1. Moisture
2. Presence of oxygen
3. Higher temperatures

The aim in seed storage is to reduce oxidation processes to slow down seed ageing and preserve seed quality as long as possible. The most important factor is the moisture level.

Figure 1 shows the effect of moisture level on the oxidation of lipids, on enzyme activity and mould growth in seeds. Between 20% and 35% equilibrium relative humidity, lipid oxidation is at the lowest level and enzyme activity is insignificant. This is therefore the ideal range of humidity levels for seed storage. The next section will provide you with background information to understand what is meant by equilibrium relative humidity.

Good to know!

Even before a decrease of germination rate becomes visible after storage, seeds begin to age and their vigour decreases, which means seed will emerge more slowly. Lower seed vigour can result in less hardy – or deformed - seedlings, which will be less tolerant to stress factors. By ensuring appropriate storage conditions, you are not only increasing the shelf life of your seeds, but also preserving seed quality!

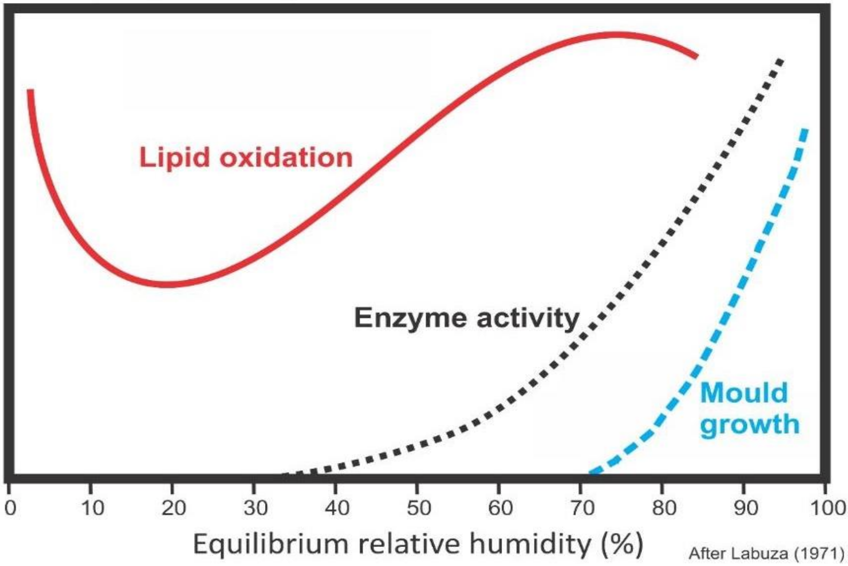


Figure 1: Oxidation, enzyme activity and moulds in relation to seed moisture level. After Labuza, TP (1971): Kinetics of lipid oxidation in food. CRC Critical Reviews in Food Science and Technology, 2: 355/405.

Drying your seeds and keeping them dry has the highest priority. If you want to optimise seed storage further, you can limit the oxygen flow around your seeds. We will see further down how to do this. Temperature is only the third factor driving oxidation and seed ageing. Rather stable room temperatures in a cool place like a cellar are fine for regular seed storage, although lower temperatures, or even freezing, allow for long-term storage.

4.3. Drying seeds

Background knowledge: Seed moisture content, relative air humidity, equilibrium relative humidity

Seeds contain a certain amount of water. This is called the **moisture content**, expressed in %, and is the proportion of water in the fresh weight of the seed.

The atmosphere in which seeds are stored (inside a jar, attic, fridge, …) also contains moisture: the **relative humidity (RH)** of the air is also expressed in %. It is an expression of the amount of water vapour in the air, relative to its maximum. Relative humidity varies greatly with temperature. If the temperature of an air mass is decreased, the relative humidity of the air increases.

The relative humidity in an environment also depends on the type of climate in each region. The average relative humidity of the ambient atmosphere in Europe is generally around 70%.

During storage, seeds equilibrate to the relative humidity of the air in which they are stored. The humidity of the seed will influence the humidity of the box, and the humidity of the box will penetrate the seed, until both balance out at their equilibrium relative humidity (eRH).

Equilibrium relative humidity is a more reliable measure of storage conditions than moisture content: seeds with a high oil content (such as cabbage seeds) will have a lower moisture content compared to seeds with a low oil content (such as pea seeds) when stored at the same relative humidity (because oil can't contain water). In addition, it easier to measure the relative humidity of the room or box where the seeds are located, than to measure the moisture content of seeds.

Drying methods

20-40% eRH are ideal for seed conservation. Several methods can be used to dry a seed batch to around 30% eRH before storage. Ventilation and heat will accelerate the drying process. Desiccant materials may also be used to dry seeds.

Natural drying: Sun and wind

At the end of the growing season, when temperatures are still fairly high and humidity levels low, the sun and wind may be sufficient to dry harvested seed batches. It is preferable to avoid direct sunlight. Seeds can be spread on racks or screens in a greenhouse or barn. Ventilating with a fan will speed up the drying process further. In this way, seeds can be dried below the ambient RH level. Keep in mind that the seed is still exposed to the relative humidity of the air. At night, when temperatures drop, the ambient relative humidity increases. Care needs to be taken to prevent the seed from re-absorbing humidity. If drying over several days, you may want to gather seeds in a heap and cover the seeds during the night and spread them out again the next morning. Beware of the risk of condensation if you cover the heap. Once dry, seeds should be collected before ambient humidity levels rise (usually in the mid or late afternoon).
If the humidity of the air is too high, or the temperatures too low, the seeds won't dry down enough in natural ambient conditions. An active drying process then becomes necessary.

Forced drying with heated air

Seed batches can be placed in large boxes or chambers and aerated with a fan. Heating the air entering the box or chamber will lower its humidity level and speed up the drying process. Beware of the risk of damaging the seeds if temperatures get too high, especially at the beginning, when seeds are still moist. It is safe to stay below 35°C.

Good to know!

When seeds dry, water needs to diffuse from their core to the outside layers. This takes time. In addition, the seed coat can retard the water release from the seed. Therefore, interval drying – not heating the air continuously, but by intervals - is more energy efficient, especially for large seeds.

Forced drying with desiccants

Humidity absorbers or desiccants can be used to dry seeds. This comes in handy for smaller seed batches that fit into a glass jar, a plastic box or barrel. This technique is also recommended in (sub)tropical regions, in which high humidity levels make drying seeds a challenge. Silica gel is easily available and practical to use. Zeolite drying beads are also available. Using calcium chloride ($CaCl_2$) is also an option, although less practical, because it cannot be regenerated for reuse and produces a liquid salt solution as it absorbs humidity.

Sheet 2 presents a seed drying box as an effective solution for seed drying, which can also be used for storage. It can be adapted to a glass jar or air-tight barrel to fit different needs in terms of seed volumes.

Sheet 3 gives you an overview of the 3 main desiccant materials available, how they work, their advantages and disadvantages.

Measuring the equilibrium relative humidity (eRH) of a seed lot

Once a seed batch has dried, it’s advisable to measure its humidity level before storage, to ensure it is dry enough for proper conservation.

Placed in an airtight container, the RH of seeds will equilibrate with the RH of the surrounding air. This can be used to measure the eRH of a seed sample with the following, simple and very affordable method. To do so, you will only need an airtight container (glass jar or hermetic box) and a hygrometer (instrument to measure the RH).

*There are different kinds of hygrometers for measuring relative humidity, which are described in **Sheet 4**.*

Figure 2: An example of measuring relative humidity of 2 wheat samples. Once they have reached an equilibrium, the one on the left is at about 20% RH and safe for storage. The one in the middle is at about 90% and requires drying. Photo: S. Groot.

The protocol is then very simple:

⇒ Fill the airtight container with your seed lot or a sample. The container should be filled with seeds, leaving as little air as possible;

⇒ Add a hygrometer and close the container. If it is a non-digital hygrometer (working with a good old needle), make sure you can read it through the container or lid when closed;

⇒ Place the container in the storage room at storage temperature;

⇒ Check the hygrometer regularly and wait until the RH stabilises. Usually eRH is reached within 24h, if the container is completely filled with seeds;

⇒ If eRH is higher than 35%, the seed must be dried again. Keep in mind that commercial hygrometers often have an accuracy of +/- 2%.

If you are measuring the eRH of a seed sample, make sure that in the meanwhile the rest of the seed lot is stored in stable conditions or in an air-tight container. Otherwise, your sample might no longer be representative of your seed lot!

4.4. Storing seeds

The first and main objective while storing seeds is to keep them dry (20-40 % RH). To further improve the conservation and lifespan of your seeds, it is advisable to limit oxygen levels. Warm temperatures favour oxidation, but temperature is only the third factor, after humidity and oxygen.

Keeping seeds dry during storage

There are two different strategies to maintain your seeds at a low humidity level. You can either pack them in permeable materials (paper or woven bags) and ensure that the atmosphere around them does not surpass 40% RH in a chamber, storage box or barrel; or you can use packaging that is impermeable to air and water vapour (glass jars, trilaminate vacuum-pouches).

Storage room, boxes and barrels
If you have access to a seed storage room where the RH is maintained at appropriate levels (usually 30-40%), the easiest is to place your seeds there in permeable bags (paper or woven bags) for storage. Such rooms or chambers with controlled RH and temperature are expensive and not often available in small-scale seed companies, community seed banks or farmers' seed networks.

For smaller seed volumes, you can maintain low humidity levels in a seed storage box, barrel or unplugged freezer as shown in ***sheet 2.***

Store your seeds in an air-tight plastic box or barrel with a humidity absorber (silica gel or drying beads) and a hygrometer you can check without having to open the box or barrel.

Good to know!

If the storage container is airtight and small (airtight box, unplugged freezer, etc.), an equilibrium of around 30% RH can be stabilised with the help of calcium chloride ($CaCl_2$) salt. At 20°C this salt provides air with an eRH of 32%. It is readily available at D.I.Y. shops for use as a moisture absorbent (dehumidifier) in caravans for instance. The calcium chloride absorbs water and maintains the eRH, until all crystals are dissolved into a watery solution.

This can be used both to dry or to store seeds. While this is a handy solution to stabilise RH at a known level, using $CaCl_2$ is less practical than silica gel or drying beads, as there is a risk of accidentally spilling the watery salt solution onto your seeds and the salt cannot easily be regenerated.

Check the hygrometer regularly (for example, once a week) to make sure the RH stays below 40%. If the RH begins to rise, replace or regenerate the humidity absorber.

Hermetic containers and pouches

Once your seeds are dry, you can simply store them in a hermetic container to prevent them from becoming moist again. Plastic boxes, bags and pouches are not hermetic to water vapour and oxygen. Glass jars with a rubber seal or bottles and jam jars with a plastisol lining in the metal cap will keep moisture from getting in. You can also vacuum-pack seeds. This has the additional advantage of removing oxygen contained in the air for optimised seed conservation under anoxic conditions. Plastic pouches used to vacuum-pack foodstuffs are not suitable. Pouches combining polymer and aluminium layers (also called mylar bags) are appropriate for seed storage.

Before storing seed in a hermetic container, make sure it is dry, below 35% RH. Otherwise, excess moisture will be locked in the hermetic container with the seed.

Reducing oxygen levels

Most experienced seed producers are well aware of the effects of moisture on seeds and the necessity to keep seeds dry. Oxygen, the second most important factor driving seed ageing (mainly caused by oxidation), is less well known. Storing seeds in a protected atmosphere, with no or hardly any oxygen, is an effective way to improve seed conservation and storage.

> **Good to know!**
>
> **A well-dried, vacuum-packed seed will not "die" due to suffocation! This is because respiration enzymes aren't active in a dry seed. However, when a seed is still moist (above 70% eRH), it is metabolically active and will be damaged if it is deprived of oxygen.**

A vacuum pump - as used in kitchens, restaurants or butcher shops - is an effective tool to vacuum-seal seeds to limit oxygen levels, provided you are using appropriate (tri-laminate polymer-aluminium) pouches. This method is very simple, relatively inexpensive, easy to share and very versatile in use. A further advantage is that vacuum conditions slow down the development of, or even kill, some seed pests, such as the weevils in pulse seeds. The disadvantage is that these materials, combining plastic and aluminium, are currently hardly ever recycled.

*Equipment for vacuum-packing is described in **Sheet 5**.*

For large volumes, techniques have also been developed to store seeds under vacuum in big-bags. Flushing with nitrogen gas, as is frequently done in the food industry, allows to remove oxygen completely, but requires specialised equipment. For cereals, conditioning in big bags is often done with CO_2. The big bag is wrapped with a gasproof bag, and the gas is injected using either a gas bottle and a special application nozzle, or dry ice. On top of removing oxygen, this treatment has the additional advantage of killing all insects present in the bag and preventing their eggs from hatching, developing, and damaging the seed.

When no vacuum-pump is available, glass jars with a metal lid and plastisol sealing can be used to reduce oxygen levels, when packed with a very limited amount of air in the jar. Completely fill the glass jar with seeds before closing. Mylar bags can also simply be heat-sealed. The limited amount of oxygen will gradually be consumed by the antioxidants that are naturally present in the seeds, creating limited harm. Oxygen-absorbers can also be inserted into the jar or bag to trap oxygen and create an anaerobic environment from the start. They are available in the form of small paper packets containing iron powder. They should not be used with seed samples below 50g, as they often also contain a moisturiser to accelerate the iron oxidation. The moisturiser will increase the eRH in the jar. With small samples next to an oxygen absorber, also some dry silica gel should be added to maintain a low eRH. Keep in mind new oxygen will enter the jar each time you open it.

Separate conditioning

During storage, it is crucial to open the container as rarely as possible, as moisture and oxygen are reintroduced each time. Ideally, it should never be opened before its final use.

If the seeds have to be reconditioned (bagging for yearly shipping, etc.), care should be taken to package quantities as close as possible to the final use. For example,

- ⇒ A 1kg seed batch intended for direct sowing on a single field can be packaged in a 1kg bag.
- ⇒ A 1kg seed batch intended for individual 1g bags, bagged at the beginning of the year, with an expected delivery of 250 bags each year, could be packed in 4 bags of 250g, one for each year of use.
- ⇒ A 1 kg seed batch for a seed bank, with small samples to be made available for distribution, could be packaged as follows: 10 X 1g, 5 X 100 g, 1X 500g.

Storage temperature

Temperature is only the third most important factor driving seed ageing. If your seeds are packed and stored at low humidity, they will be more tolerant to higher temperatures, as illustrated by James' Rule, which is a rule of thumb to estimate if a given environment is appropriate for seed storage:

Temp (°C) + RH (%) < 60

According to this rule, seed at 35% RH can tolerate temperatures up to 25°C without being damaged too much. By contrast, seed storage conditions above 10°C may be harmful to seed stored at 50% RH. If you have dried your seeds and are keeping them dry, you can store them safe in a cool place like a cellar or basement at around 15-18°C.

Figure 3: In this refrigerator, relative humidity is at about 65% - too high for seed storage in permeable bags.

Wondering whether it is a good idea to store seeds in a refrigerator? Remember that the relative humidity of the air increases when the temperature decreases. In a refrigerator or a cold room (without moisture extraction) the RH can be rather high, too high for proper seed storage! If seeds are packed in a permeable paper or fabric bag, the moisture will penetrate the seeds. If the dry seeds are in a container impermeable to moisture, they can be placed in a refrigerator or cold room without such a problem. Take care when you retrieve your sample from the cold storage. Water may condense on a cold surface: if it's on the outside of the jar, this is not a problem provided you open the jar after warming it to room temperature, so the seeds stay dry.

The table below indicates how long you can expect to conserve seed in good storage conditions, according to species. If you are already obtaining similar shelf lives to the ones indicate, your storage conditions are probably already rather good. If you want to store seed longer than that, you will need to consider vacuum-sealing or even freezing it.

The indicative number of kernels per gram of seeds will help you to decide on how to pack the seeds into sub-batches that will fit your needs.

Table 1 shows indicative expected lifespans of seed of different vegetable species under good storage conditions, as well as average numbers of kernels per gramme of seed. Adapted from Semae Pédagogie, 2023 (www.semae-pedagogie.fr).

Crop species	Indicative lifespan of seeds in good (dry) storage conditions (years)	Number of kernels per gramme
Aubergine / eggplant	6 - 7	250
Beetroot	6 - 9	50 - 80
Cabbage / kale	4 - 5	300 - 800
Carrot	4 - 5	700 - 1200
Celery	8	2500 - 3000
Chicory / endive	6 - 8	600 - 800
Common bean	3	2 - 6
Cucumber	6	30 - 35
Faba bean	6	2
Lamb's lettuce	5	600 - 1000
Leek	2 - 3	300 - 400
Lettuce	5	800 - 1100
Melon	5 - 10	35
Onion (yellow)	2	250 - 300
Parsley	3 - 5	400 - 800
Pea	3 - 4	3
Radish	5	80 -120
Spinach	5	90 - 100
Squash / pumpkin / zucchini / courgette	5 - 7	3 - 10
Tomato	4	250 - 450
Turnip	5	450 - 700

Special cases: ultra-dry state and freezing

Below 15% eRH, seeds are in an **ultra-dry** condition. This situation, in the presence of oxygen and at room temperature, induces a more rapid degradation of seeds and a loss of germination power. It is therefore not recommended to over-dry seeds if they are to be stored under normal conditions.

However, this is not a problem if seeds are vacuum-sealed and frozen. In any case, seeds intended for **freezing** should be below 40% RH, preferably below 30%. Storing hermetic packages of seeds in a regular kitchen freezer (-20°C) is an effective way of keeping dry and well-conditioned seeds for a very long time. When taking a sample from the freezer, wait a few hours until the seeds are warmed before opening the package, to avoid condensation of water vapour on the seeds. Freezing is appropriate for long term storage, not for seed batches you will need to tap into regularly, as repeated thawing and re-freezing may harm the seed.

4.5. Before sowing: avoiding imbibition injury

Dry seeds below 35% eRH are not fit for sowing right away! Taking them right from the storage to sow them in moist soil might cause imbibition injury to the seeds when the soil is cold. If you take a seed lot from seed storage one or two days before sowing and place it in an open or permeable bag or container, seeds will have time to take up moisture and equilibrate with the surrounding air. If you are in a hurry, place the seeds overnight in an open package or cup in a closed box with a wet cloth.

4.6. RECAP on seed storage

If you regularly end up throwing away seeds that initially were vigorous and healthy, you need to improve their drying, packaging and storage conditions. Let's start with the order of importance of the variables:

- It is **essential** that seeds are dry and stay dry!
- It is **beneficial** that they are protected from oxidation!
- It is **preferable** to store them at a constant and relatively cool temperature.

- Several methods can be used to dry seed batches: natural drying with the sun and wind, forced drying with heated air and ventilation or using desiccants. You can of course combine different methods, according to weather conditions and seed volume.
- Check the eRH of your seeds before storage, to make sure they are below 35% eRH.
- If you do not have a cold room with a controlled moisture level below 40% RH, take special care to dry the seeds and keep them dry. Then, simply place them in the driest, coolest, darkest and most stable place possible. For example, drying and vacuum-packing seeds is by far preferable to a jar that is regularly opened – letting moisture in - and then put back into the fridge.
- Reducing oxygen levels is a good means to further improve seed conservation. A vacuum pump and a pile of mylar pouches might be a good investment. A set of glass jars in different sizes and oxygen absorbers are another alternative.
- Package seeds according to your use, for example according to the quantities you will be distributing every year.
- When taking seeds out of dry storage (20-35% RH) for sowing, equilibrate them to a higher RH to avoid imbibition injury.

Figure 4 summarises the options and decisions when drying and storing seed.

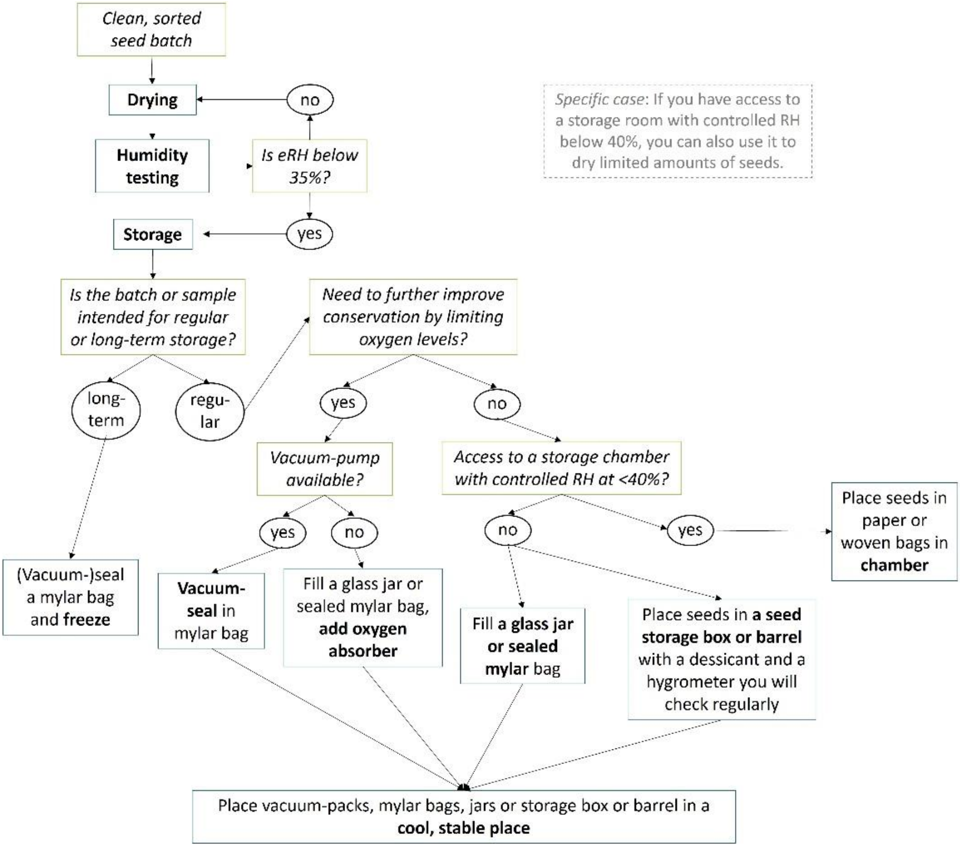


Figure 4: Decision scheme for seed drying and storage summarising the different options according to available equipment.

5. Setting up your action plan

Now that the different drying and storage issues are clearly identified, we have the necessary background knowledge to optimise seed conservation in different contexts. Before setting up your own action plan, let's first go back to the example cases from section 1 and see what they implemented to meet their objectives of improved seed conservation.

Example 1: Josette selects and harvests seeds of 10 varieties of tomatoes for an amateur exchange network.

Objective: There is no additional conservation objective to implement, as this would be a waste of time and money.

Action plan: Nothing to do.

Example 2: Bohuslav participates in a farmers' network.

Objective: To achieve onion seed conservation conditions over 6 years, with a usage of 2kg per year, distributed among 6 farmers.

Action plan:

⇒ After harvesting, pre-drying the umbels and threshing 15 kg of onion seed, first drying in the barn on racks for one week.

⇒ After drying, place the seeds in an **air-tight barrel with 8 cloth bags of 500g of dry silica gel each**, until the hygrometer has dropped to 35% for at least four days.

⇒ After drying, take the sealed barrel in the car, and drive down to the village grocery shop to **vacuum-pack** the seeds (there is no electricity at the farm but there is a vacuum machine at the grocery shop), remember to make an appointment and bring honey in exchange. Bohuslav uses humidity and oxygen-proof mylar pouches.

⇒ The harvest of 15 kg of seeds will be sufficient for 6 years. They are **packed according to the 6-year cultivation plan**: 4 farmers at 250g and 2 at 500g per year. From the remaining 3 kg, 10 x 2g are prepared for germination testing. The rest is subdivided into 6 bags of about 500g, as an extra reserve.

⇒ The vacuum bags are then labelled with the year of production and the name of the variety.

⇒ They are placed in 6 paper bags, labelled with the year when they will be used, and brought to the network's storage area, where they will be **stored at ambient temperature or cooler**. Storing the seeds this way, under dry, low-oxygen conditions, is usually sufficient to conserve seed for 6 years at ambient temperature. Nevertheless, Bohuslav may freeze the seed bags for the last two years, just to make sure.

Example 3: SuperSeed is non-profit seed enterprise that selects, maintains and multiplies organic seeds of traditional local varieties under artisanal, low-input conditions.
The current economic situation of the enterprise does not allow for investment in a cold room with controlled relative humidity below 40% for seed storage.

Objective: Optimal storage conditions for the entire stock in order to increase the shelf life and the time to market each seed batch.

Action plan:

⇒ Harvesting of each variety is planned as closely as possible according to seed maturity and the availability of staff and equipment for threshing and sorting.
⇒ After harvesting and threshing the seeds, seeds are dried in a greenhouse. If thorough cleaning and sorting is not possible immediately, the seeds are at least pre-cleaned to remove plant residues and most weed seeds, dried and temporary stored under conditions that keep the seeds dry.
⇒ SuperSeed built a **batch dryer**, consisting of several large wooden boxes with wire mesh base, that can be piled up and ventilated with heated air. After the first drying step in the greenhouse, the seeds are cleaned, sorted and placed in the batch dryer for an extra active drying, if deemed necessary.
⇒ After drying, the **eRH of the seeds is checked** to be at most 40%. A sample of each batch is tested using a hermetic jar and hygrometer, while the rest of the batch is protected from taking up moisture in the meantime, in the same room. If the eRH of the sample is above 35%, the seed batch goes back into the batch dryer for active drying, or dried by hermetic storage with silica gel, depending on the seed lot size. If it is below 35%, it can be conditioned for storage.

- ⇒ When seeds are dry enough, small and medium-sized seed batches are subdivided and **vacuum-packed** into trilaminate pouches according to specific instructions for each variety, depending on the expected amount of seed that will be sold each year and how often they are bagged into final commercial seed packets (if no specific indication: 10 x 5g for germination tests and the remaining batch in portions of 100g)
- ⇒ The young enterprise cannot afford equipment and service providers that vacuum-pack bulky seed lots into big-bags. Therefore, bulky lots, such as pulses or sunflowers, are stored in **120l air-tight plastic barrels**. A digital, bluetooth connected hygrometer is placed in the barrel, allowing to check the humidity level without opening the barrel. If humidity levels begin to rise, meaning the barrel is not completely hermetic to moisture, the barrels are opened and regenerated silica gel (2 bags of 500g each) is added. This solution for bulky seed lots is not completely satisfactory, but good enough while SuperSeeds awaits to afford a storage chamber with controlled RH.
- ⇒ Pouches and barrels are all labelled with the year of production, the name of the variety and the batch number. After each germination test, the germination rate of each batch is noted both in the internal digital database and a paper notebook.
- ⇒ To reduce plastic waste, SuperSeed decided to use paper pouches as final packaging for commercial seed packets. As there is a risk of seeds taking up humidity in paper pouches, reducing the storability of seeds by clients, **SuperSeed provides its clients with recommendations for seed storage**, including instructions on how to assemble a seed storage box.

Your turn: Set up your own action plan!

Go back to the objectives you set in Action Plan 1. **Define the steps and means to achieve your conservation objectives.**

Based on your objectives, determine what steps you need to take to dry the seeds, keep them dry, condition them in appropriate portions, and store them in good conditions. **Be as precise and detailed as possible.**

This means setting up strict and binding procedures to meet the objectives. To avoid future excuses like "we didn't have time" or "we forgot", you should **list simple, practical and successive steps, possibly in a checklist**.

Then, get organised to follow the procedure and **make a list of the materials needed for the plan that are not yet available.**

6. Get equipped and organised!

The technical and financial aspects of implementing seed saving objectives should not discourage you. In many cases, seed conservation and shelf life can be improved significantly with just a few pieces of simple and rather affordable equipment. It can probably even be shared with others.

Your turn: Get equipped!

Start by making a list of the equipment needed, including machinery and consumables. You may use the practical information sheets at the end of this document for information.

Questions to ask concerning each equipment include: Can the equipment be shared? Is it necessary to have it close by? How many days per year will it be used, and will the use be urgent and unpredictable? Are there service providers in your region, e.g., for vacuum packing?

Now look at the size and range of the equipment, what volume of seeds, what total quantity of bags, jars, boxes or barrels, and what intensity of use?

If the equipment requires too big an investment, you may want to seek financial support: participatory financing, foundation donation, institutional or community grants.

7. Conclusion & Practical Info Sheets

This practical guide is intended to help professional, semi-professional and hobby seed growers improve their seed storage practices. After all the significant effort involved in cultivating seed crops and harvesting seeds, it is good to go all the way and ensure decent storage conditions.

In the following, you will find practical information sheets to help you plan how to improve seed storage conditions and information on equipment.

PRACTICAL INFO SHEETS:

Sheet 1: Summary table of improvement objectives

Sheet 2: Seed drying and storage box (or barrel)

Sheet 3: Overview of desiccant materials for seed drying and storage

Sheet 4: Hygrometers

Sheet 5: Vacuum sealers and oxygen absorbers

Practical Sheets

Sheet 1 - Summary table of improvement objectives

Crop and Variety	Quantity produced per year of production	Frequency of multiplication	Quantity sold or distributed per year	Effective shelf life (with sufficient germination)	**Objective for improvement**

Determining questions

- ➔ Quantity produced

  Is it determined by the size of the seed crop (as it is often the case with celery, for example, which is an allogamous crop and has a high multiplication rate) or because of market demand (as for example bean or tomato, who have lower multiplication rates)?
  If there is actual overproduction, marketing should be improved, in addition to storage.

- ➔ Frequency of multiplication

  Is the frequency determined by the demand, by shelf life, or by the need for rotation?
  Optimising seed conservation (shelf life) and adjusting the acreage of your seed crop according to the demand may enable you to decrease multiplication frequency and to space out the rotations.

- ➔ Quantity sold or distributed

  Am I sometimes out of stock because the germination rate is no longer satisfactory?
  If there is a shortage due to a lack of quality, then storage should be improved.

- ➔ Shelf life

  Do I ever throw away stock because the germination rate is no longer satisfactory?
  If there is a loss of production due to quality, the storage should be improved. As an alternative, maybe you can reduce the amount of seeds produced at each multiplication cycle.

<u>Sheet 2</u> - Seed drying and storage box (or barrel)

[1] A plastic box containing a desiccant material (see <u>sheet 3</u>) can be used to **maintain seeds dry during storage**. A Bluetooth hygrometer (see <u>sheet 4</u>) is used to monitor air humidity. If air humidity rises above 40%, the desiccant material is changed for fresh material.

[2] The same principle can be used to **dry seeds before storage**. Ventilate with a small fan and spread seeds in a thin layer to accelerate drying. Make sure you use enough desiccant material to dry down the seeds and use the hygrometer to monitor the drying process.

[1]

[2]

Use a box with a fairly air-tight lid. Some boxes sold specifically to keep equipment dry in caravans, for example, already come with a bag of silica gel and integrated hygrometer. They can be handy to store seeds. Place the box in a place with stable, cool temperatures.

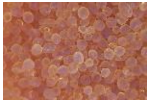
Photo: Kew Gardens' Millennium Seed Bank, Technical Information Sheet 08

A plastic barrel filled with dry silica gel also works. It is best to use a barrel just big enough to contain seeds and silica gel.

If you are drying seeds, half as much silica gel as seeds (in weight) will usually be more than enough. For example, if you want to be on the safe side and make sure to remove 1kg of water from a batch of 10kg of seeds (i.e., reducing the moisture content by 10%) and consider dry silica gel adsorbs at least 25% of its weight, you need 4kg of silica gel.

You can do the same for a smaller seed sample in a glass jar. Here about 600g of pepper seed with 400g of silica gel in a nylon stocking.

Sheet 3: Overview of desiccant materials for seed drying and storage

	 **Silica gel**	 **'Zeolite' drying beads / Molecular sieves**	 **Calcium chloride ($CaCl_2$)**
How it works	It is a synthetic form of silicon dioxide with a very porous structure. It traps water vapour by adsorption, which means that water molecules adhere to its surfaces. It equilibrates with the environment, meaning adsorbing moisture from more humid material or releasing moisture towards drier material	Made of modified ceramic materials (aluminium silicates or "zeolites"), they adsorb and hold water molecules in microscopic pores. They continue to absorb water until all of their pores are filled, up to about 20% of their dry weight.	At 20 °C this salt provides in a pure form, air with an eRH of 32%; attracting water until it is completely dissolved.
Advantages	- Readily available - Often contain a colour indicator that changes colour when the gel is saturated - High adsorption capacity: At 50% RH, it can adsorb at least 30% of its own weight in water. - Can be regenerated / dried in an oven at about 140°C (check product specifications) to be reused	- Rhino group developed zeolite beads especially for seed applications. Although it doesn't currently supply to Europe, the following website provides much technical information: www.dryingbeads.org - Can be regenerated/dried by heating at >250°C for 3-4 hours - Adsorb water vapour more quickly than silica gel	- Useful to stabilise seed at 32% RH (or at another level if mixed with specific additives) - Attracts a high amount of water proportionally to its weight

Disadvan-tages / precaution	- Silica gel containing toxic cobalt (blue) is no longer authorised for sale in the EU. - Silica gel dust generally may be hazardous. Check the Safety Data Sheet of your product.	- More costly than silica gel - Regeneration requires higher temperatures and longer time than silica gel - No colour indication when saturated - Quick adsorption, careful not to over-dry	- Cannot easily be regenerated - Produces salty water once dissolved, which may accidentally spill. Some suppliers offer salts mixed with gelling agents to avoid this.
Providers	Widely available from online shops	Zeolite beads are also available online as molecular sieves. Go for pore size 4Å to adsorb water vapour from the air.	Widely available in online shops and in some DYI shops.

Materials like natural zeolites, bentonite clay, dried rice or charcoal also have desiccant properties that may be useful for drying seeds. However, we don’t have technical data for them, nor practical experience with them.

<u>Sheet 4</u>: Hygrometers

Hygrometers measure relative humidity. They are useful both for testing a seed sample's equilibrium relative humidity (as explained on p. 15 of this booklet) and to monitor relative humidity in a seed drying or storage box (see *sheet 2*).

There are all sorts of instruments on the market for measuring hygrometry. Many of them also measure temperature. Main differences are: mechanical (hair hygrometer) or digital; whether they can be read remotely or not; and whether they record data over time or not. They all have advantages and disadvantages, choosing among them will depend on how you will use your hygrometer(s).

Hair hygrometer: Mechanical hygrometer with natural or synthetic hair

A needle indicates relative humidity on a scale. You can place it in a transparent plastic seed storage box, so that you can read the display through the plastic. They can also be fit into storage boxes, like the one you see in the picture on the right.

Digital hygrometers measure air humidity through a sensor. The sensor can either be integrated with the display or connected to it by a cable or by a wireless connection. Their disadvantage is that they depend on electricity and a battery. Wireless models are especially convenient to check the relative humidity in a non-transparent container without having to open it, such as a seed storage barrel, for example. Those who connect to Wi-Fi can even be consulted remotely from a mobile phone or computer.

The price of hair or digital hygrometers range from a few euros to a few hundred euros, depending on brand, accuracy and functionalities. The lower price range may be less accurate. If you acquire several of them, you can measure the air humidity in the same place with all of them to find those who are too far off-target and discard those.

Some bluetooth digital hygrometers come with a **data-logger**, which stores data at regular intervals (e.g. every minute, every 15min or every hour...) over time. This is useful if you want to know exactly how the hygrometry evolved over time, for example if you want to compare the drying curves when using two different drying techniques. The bleutooth enables reading the data logger on distance and from a visually closed container.

Sheet 5: Vacuum sealers and oxygen absorbers

Vacuum-sealing is a simple and efficient way to keep seeds dry and reduce oxygen levels around the seed. Be mindful of two things when vacuum-sealing:

- ✓ Make absolutely sure your seeds are dry (less than 35% eRH), otherwise you will trap moisture with the seed.
- ✓ Use pouches of trilaminate material, which is hermetic to air, water vapour and oxygen. Also known as *mylar*, this material is a combination of thin polymer (plastic) and aluminium layers. Plastic pouches as used in home kitchens or butcher shops are not appropriate, as humidity and oxygen eventually get in.

Trilaminate polymer-aluminium pouches are available in diverse sizes and colours, for example in different online shops.

Suction vacuum sealers designed for amateur kitchens won't work to vacuum-seal aluminium pouches, because they require embossed pouches. You need to use a chamber vacuum sealer, which can also regulate the vacuum level more precisely. Prices for new chamber vacuum sealers vary from a few hundred to several thousand euros. Many butcher shops or other artisanal food processors have them, maybe you can arrange to share the machine for occasional use.

If you don’t have access to a vacuum sealer, mylar pouches can also be heat-sealed, for example with a clothes’ iron. Another option is to fill seeds into **glass jars** with hermetic rubber seals or jam jars with a metal lid, leaving as little spare space and air as possible.

To create a low-oxygen atmosphere in glass jars or heat-sealed mylar bags, you can add an **oxygen absorber**, which is usually composed of iron powder in a small paper packet. They exist in different sizes, expressed as how many cubic centimetres (cc) of oxygen they will absorb. For example, 200cc oxygen absorbers will remove 200 cc of oxygen from the atmosphere. As the normal atmosphere on earth contains 20,5% oxygen, this is enough to absorb the oxygen in a 1L jar (1L = 1000 cc).

You may want to add an **oxygen indicator**, which reacts to the presence of oxygen by changing colour. For example, the indicator might change colour when the oxygen level reaches 0,05% by volume. Obviously, this only works if you can see the colour indicator through the glass jar.

8. References & further information

Dadlani, Yadava (editors), 2023: Seed Science and Technology - Biology, Production, Quality. Springer.

- Open source book with lots of background information, available for download: https://doi.org/10.1007/978-981-19-5888-5

Kew Gardens' Millennium Seed Bank's resources available at https://brahmsonline.kew.org/msbp/Training/Resources

- Precise technical sheets on Measuring seed moisture status using a hygrometer (sheet 5), Selecting containers for long-term seed storage (sheet 6), Low-cost monitors of seed moisture status (sheet 7), Small-scale seed drying methods (sheet 8), and more.
- Technical video on Measuring Seed Moisture with a Hygrometer

Liveseed project's Practice Abstracts

⇒ On seed vigour: https://www.liveseed.eu/wp-content/uploads/2020/11/PA30_Seed-vigour-keep-it-high.pdf

⇒ On Proper Seed Storage: https://www.liveseed.eu/wp-content/uploads/2020/11/PA25_Proper-seed-storage.pdf

Seed Information Database, a compilation of seed biological trait data hosted by the Society for Ecological Restoration (SER): https://ser-sid.org/

UC Davis, HortCRSP, USAID, 2018 : Protocol for post-harvest seed drying and storage using zeolite desiccant beads, https://horticulture.ucdavis.edu/information/protocol-postharvest-seed-drying-and-storage-using-zeolite-dessicant-beads

⇒ Precise protocol for using and regenerating zeolite drying beads

... Documents available in French:

FNAMS (2020), available online upon registration:

Guide pratique La récolte des semences,
https://www.fnams.fr/ressources/guides-pratiques/guide-pratique-recolte/

Guide pratique Le Séchage des Semences,
https://www.fnams.fr/ressources/guides-pratiques/guide-pratique-sechage/

Semae Pédagogie: Durée de vie des graines et nombre de graines dans un gramme de semences (*Lifespan of seeds and number of kernels per gramme*). https://www.semae-pedagogie.org/mediatheque/

All online resources accessed October 19th, 2023

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Co-funded by
the European Union

Funded by the European Union, the Swiss State Secretariat for Education, Research and Innovation (SERI contract number 22.0412) and UK Research and Innovation (UKRI). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA, nor SERI or UKRI.

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